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Wave Response of Proposed Improvements to the Small Boat Harbor at Maalaea, Maui, Hawaii

by Linda S. Lillycrop, Steven M. Bratos,
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Coastal Engineering Research Center

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Prepared for Headquarters, U.S. Army Corps of Engineers

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U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
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Final report

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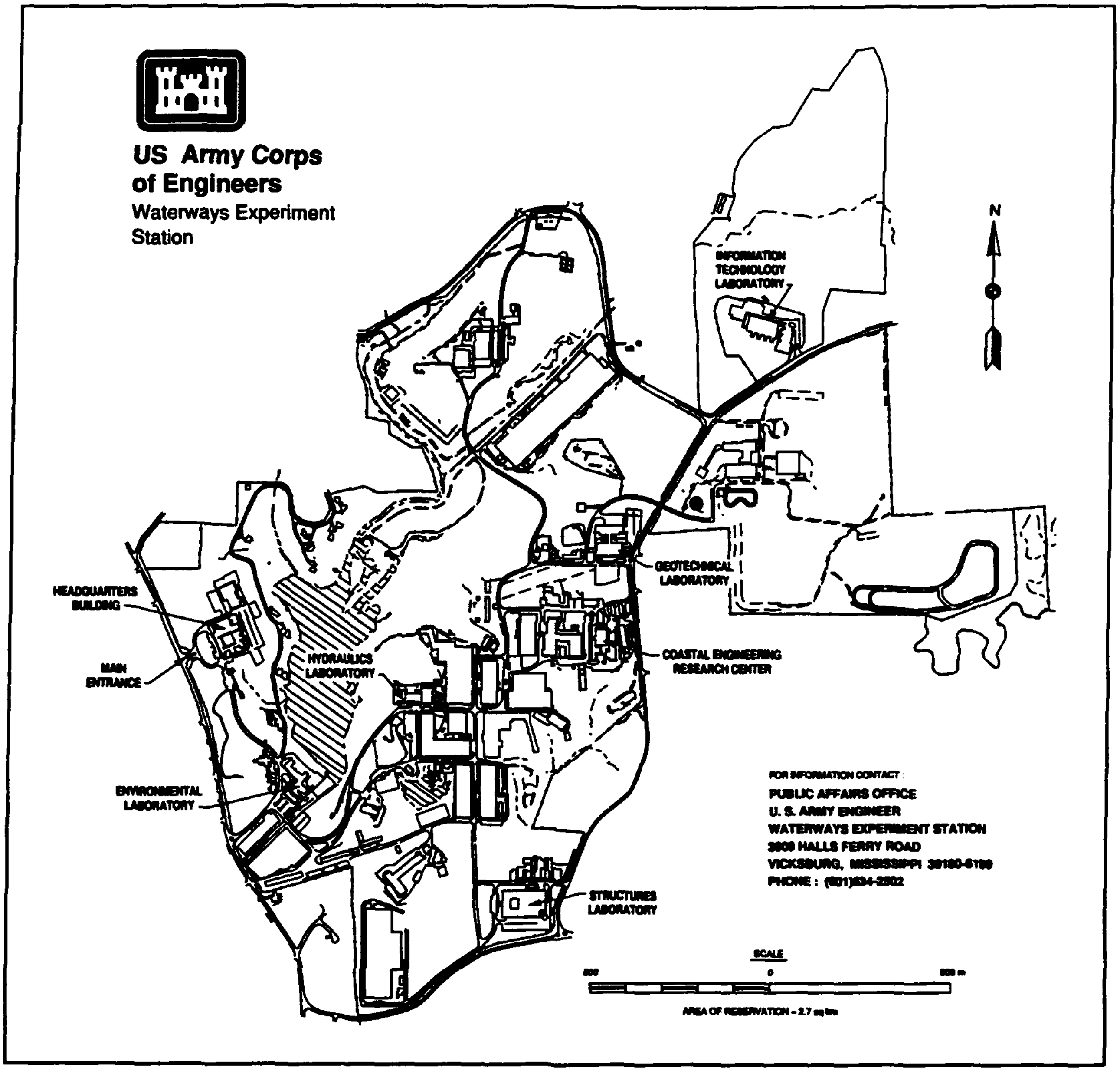

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Contents

Preface

This study was authorized by the US Army Engineer Division, Pacific Ocean (POD), and was conducted by personnel of the Coastal Oceanography Branch (COB), Research Division (RD), Coastal Engineering Research Center (CERC), of the U.S. Army Engineer Waterways Experiment Station (WES). The first study phase was conducted during the period June 1990 - September 1991. The second phase (Plans 1a and 1b) was conducted during October through December 1992. Messrs. George Young and Stanley Boc, POD, oversaw progress of the study.

This report was prepared by Ms. Linda S. Lillycrop, Mr. Steven M. Bratos, Dr. Edward F. Thompson, and Ms. Panola Rivers, COB, under the direct supervision of Dr. Martin C. Miller, Chief, COB, and Mr. H. Lee Butler, Chief, RD. The report was prepared under the general supervision of Mr. Charles C. Calhoun, Jr., Assistant Director, CERC, and Dr. James R. Houston, Director, CERC.

The assistance of Dr. Robert E. Jensen, RD, and Mr. Paul D. Farrar, COB, is deeply appreciated. Messrs. Antonio Baptista, and Paul Turner, Oregon Graduate Institute (OGI), developed grid generation software and assisted in implementation of the software used in this study.

At the time of preparation of this report, Dr. Robert W. Whalin was Director of WES. COL Leonard G. Hassell, EN was Commander.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	13,277.1	square meters
degrees (angle)	0.01745329	radian
feet	0.3048	meters
mile (US Statute)	1.6093	kilometers
nautical mile	1.852	kilometers
pounds	2.2046	kilograms

1 Introduction

Background

At the request of the U.S. Army Engineer Division, Pacific Ocean (POD), a numerical model wave response study of proposed improvements to Maalaea small boat harbor was conducted by the U.S. Army Engineer Waterways Experiment Station's (WES's) Coastal Engineering Research Center (CERC). The study was conducted to determine an optimal design plan of improvement which would provide the harbor with adequate protection from the incident wave climate. The existing harbor facility consists of an entrance channel, turning basin, two protective breakwaters, 93 berths, a haulout and launching ramp, and a 100,000-lb[1] capacity cold storage plant. Following evaluation of the existing harbor, five proposed design plans of improvement were investigated.

Study Location

Maalaea small boat harbor is located on the southwest coast of the island of Maui, HI, the second-largest island in the Hawaiian chain. The harbor is approximately 7 miles south of the County seat in Wailuku and approximately 8 miles south of the commercial and business center of Kahului (Figure 1).

The shoreline of Maalaea Bay is part of an isthmus connecting two inactive volcanos which form west and east Maui. The shoreline is characterized by a long narrow coral-sand beach and includes the world-renowned Maalaea Pipeline surfing area. Maalaea Harbor is located at the extreme west end of this beach.

Maalaea Harbor was first developed by the Territory of Hawaii in 1952. The harbor was modified in 1955, 1959, and to the present configuration in 1979 (Figure 2). The existing facility consists of a 90-ft-wide, 12-ft-deep

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[1] A table of factors for converting non-SI units of measurement to SI units is presented on page v.

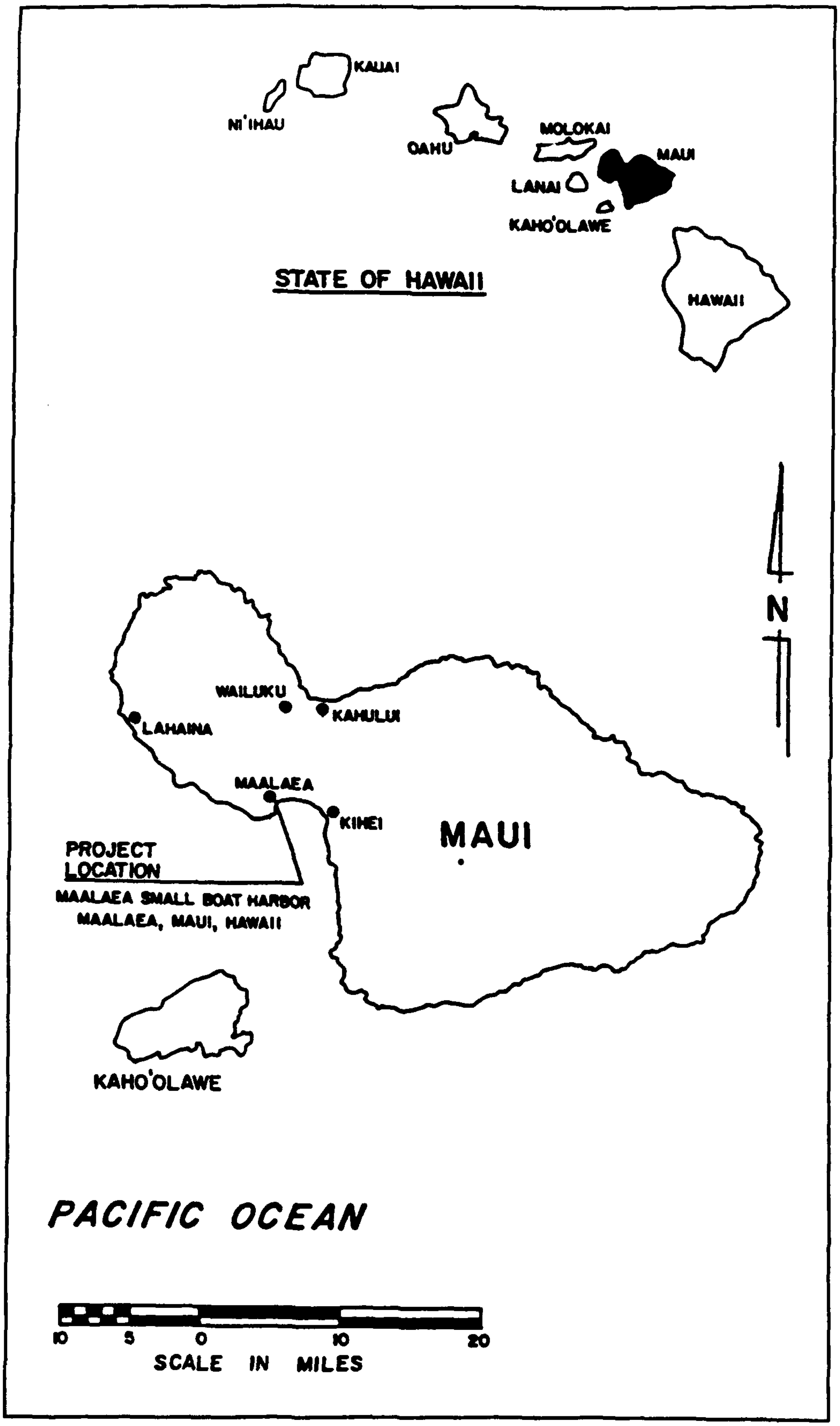

Figure 1. Study location

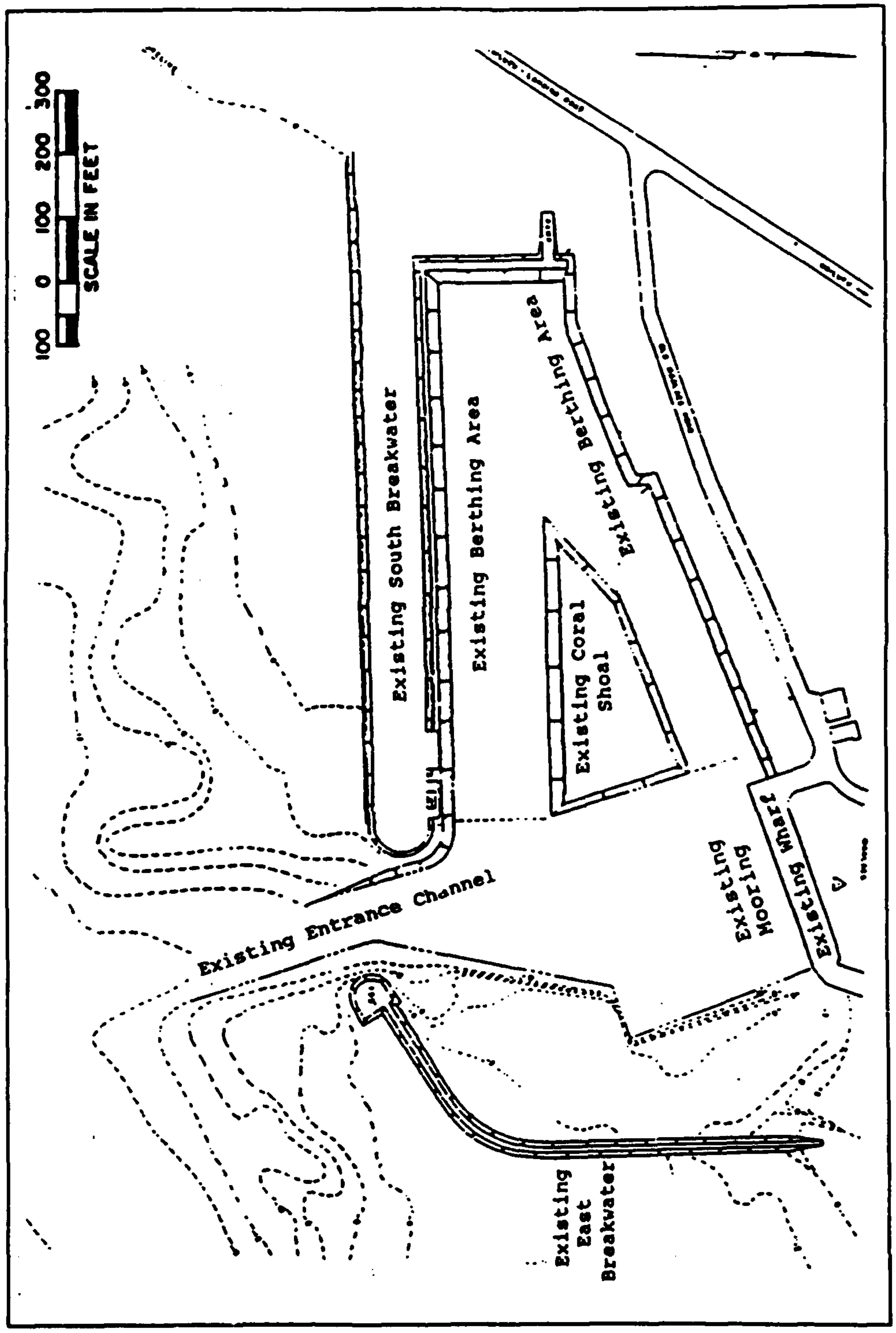

Figure 2. Existing plan

entrance channel; an 11.3 acre dredged basin; a 100-ft-long, 90-ft-wide breakwater and revetment on the south side of the basin; an 870-ft-long breakwater on the east side of the basin; and a 300-ft-long, 50-ft-wide paved wharf on the north side of the basin. The capacity of the harbor is limited to 93 small craft due to hazardous conditions. A 100,000-lb-capacity cold storage plant was constructed for use by commercial fishermen operating out of Maalaea Harbor. A launching ramp is located at the west end of the harbor basin. A U.S. Coast Guard cutter is stationed at Maalaea Harbor.

Maalaea Harbor experiences problems which include severe harbor surge, entrance channel navigation difficulties, and inadequate harbor facilities. The surge results from the existing configuration and alignment of the harbor entrance, which allow direct wave propagation through the channel opening. Surge problems cause navigational hazards and prevent safe berthing in some portions of the harbor.

Proposed improvements to Maalaea harbor are limited by several constraints. The most significant is that the harbor site is fixed and alternate sites can not be considered. Constraints mandated by harbor users and local surfers include: (a) the existing breakwater structures must remain intact and changes to the structures must be additive; (b) construction of modifications must be accomplished without serious interruption of harbor navigation; and (c) additional structures must not extend beyond the present eastern harbor boundary in order to avoid impacts on the surfing area outside the harbor. In early 1980, a hydraulic model study was conducted at WES to investigate the stability of various breakwater cross sections considered in the proposed plans of improvement. Details of the study are provided in Carver and Markle (1981). The General Design Memorandum (GDM) for Maalaea Harbor for Light-Draft Vessels (U.S. Army Engineer District, Honolulu 1980) contains a record of the research and planning which led to proposed design improvements, Plan 1 (Figure 3).

Plan 1 will provide berthing facilities for approximately 310 small craft, and includes the following improvements:

a. A 620-ft-long extension to the existing south breakwater.

b. An additional 400-ft-long revetment on the seaward side of the existing south breakwater.

c. A 610-ft-long entrance channel varying in width from 150 to 180 ft, and varying in depth from 12 to 15 ft.

d. A 1.7-acre, 12-ft-deep turning basin.

e. Removal of 80 ft from the existing east breakwater head.

f. A 50-ft-wide, 720-ft-long interior revetment adjacent to the existing east breakwater.

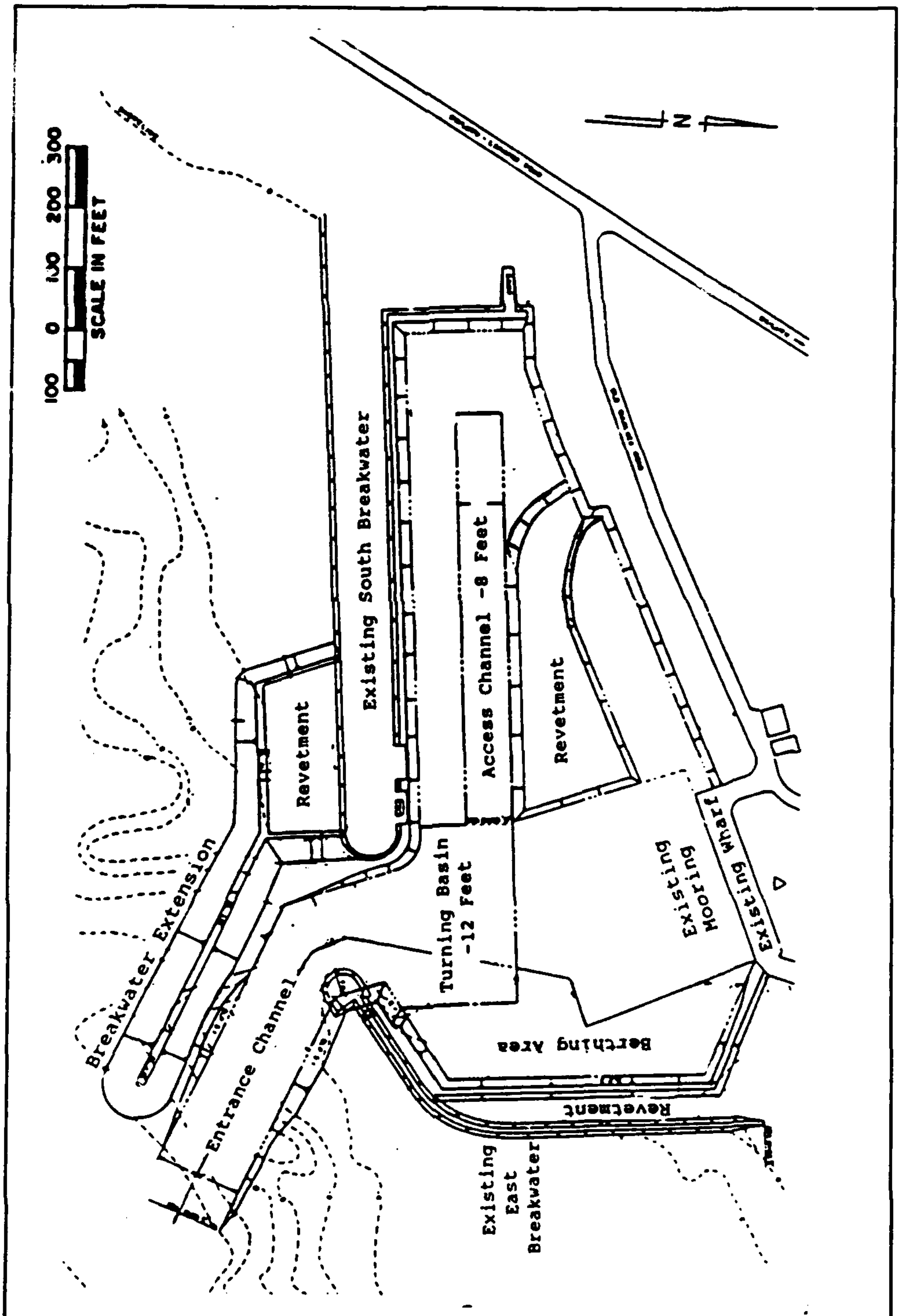

Figure 3. Proposed Plan 1

g. An 8-ft-deep berthing area adjacent to the existing east breakwater.

h. A 570-ft-long interior revetment varying in width from 50 to 170 ft.

Plan 2 (Figure 4) redirects the entrance channel to the west and includes the following improvements:

a. Removal of 300 ft from the existing south breakwater tip.

b. A 610-ft-long 15-ft-deep entrance channel, varying in width from 150 to 200 ft, and varying in depth from 12 to 15 ft.

c. A 1.7-acre, 12-ft-deep turning basin.

d. Removal of 80 ft from the existing east breakwater head.

e. A 600-ft-long extension to the existing east breakwater.

f. A 50-ft-wide, 600-ft-long interior revetment adjacent to the existing east breakwater.

g. An 8-ft-deep berthing area adjacent to the existing east breakwater.

h. A 570-ft-long interior revetment varying in width from 50 to 170 ft.

Plan 3 (Figure 5) includes the same improvements as Plan 2 with the exception of an additional extension to the existing east breakwater. The 600-ft-long extension will continue an additional 250 ft towards the west.

Two additional plans were considered in the second phase of this study (Figure 6). They are modifications of Plan 1. Plan 1a is the same as Plan 1 except the new south breakwater extension and entrance channel are rotated clockwise 7 deg. Plan 1b is identical to Plan 1a except a vertical sheet-pile bulkhead replaces the revetment along the east side of the center mole.

Headquarters, U.S. Army Corps of Engineers (HQUSACE) and POD established the following study objectives: Verify that the proposed harbor design improvements meet the criteria that wave heights not exceed 1 ft in berthing areas and 2 ft in the entrance and access channels and turning basin more than approximately 10 percent of the time per year. Develop a final design plan that satisfies the locals to the harbor and adjacent areas. To accomplish these objectives, the HARBD numerical harbor wave response model (Chen and Houston 1987) developed at CERC was used to test the existing harbor configuration and proposed Plans 1, 2, and 3. The existing configuration was tested to establish harbor response to waves for existing conditions. The three proposed plans were tested since the final design plan must meet the aforementioned constraints. Subsequently, POD requested testing of the two modifications to Plan 1 (Plans 1a and 1b). The proposed plans will hereafter be referred to as "Plan 1", Plan 2", "Plan 3", "Plan 1a", and "Plan 1b."

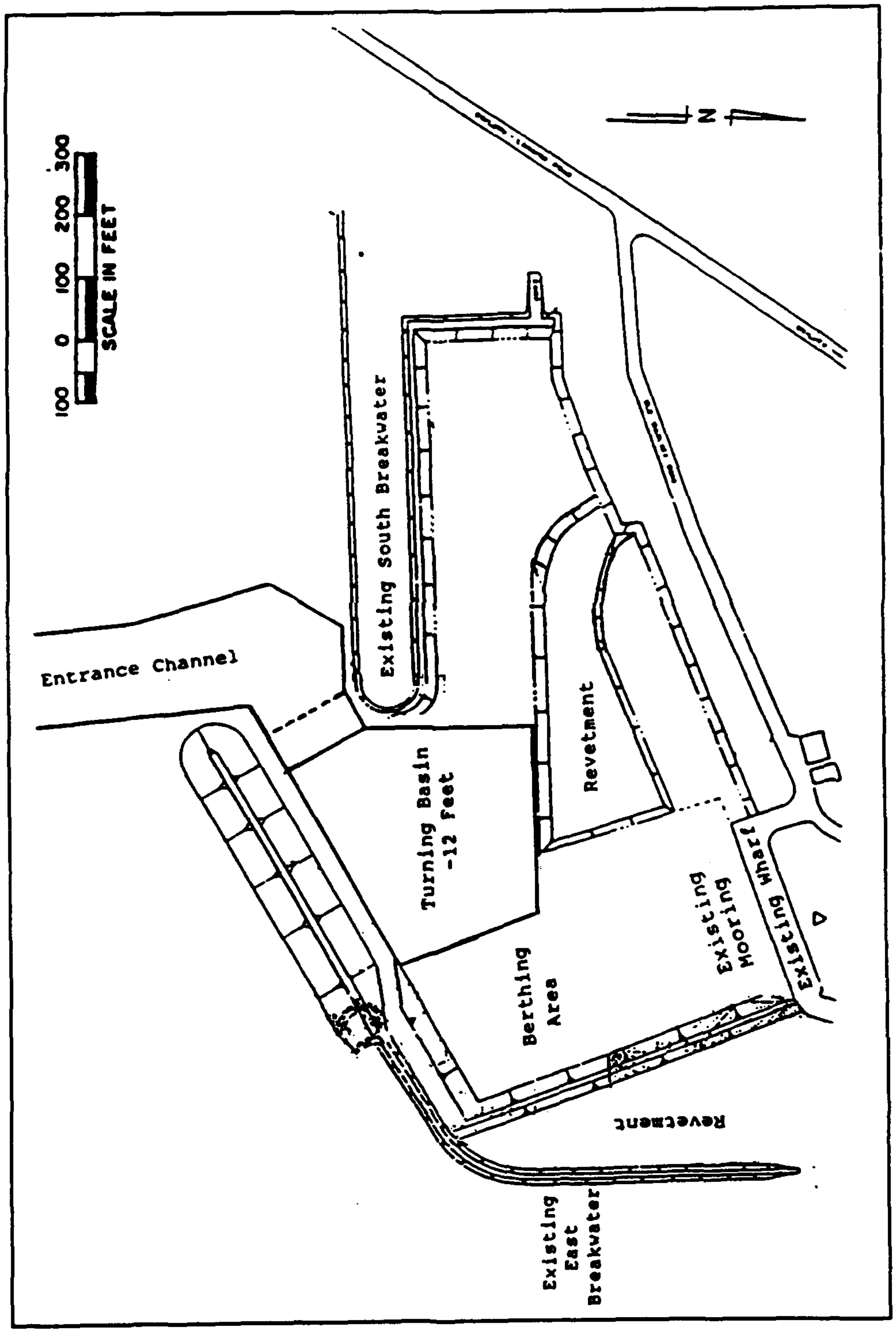

Figure 4. Proposed Plan 2

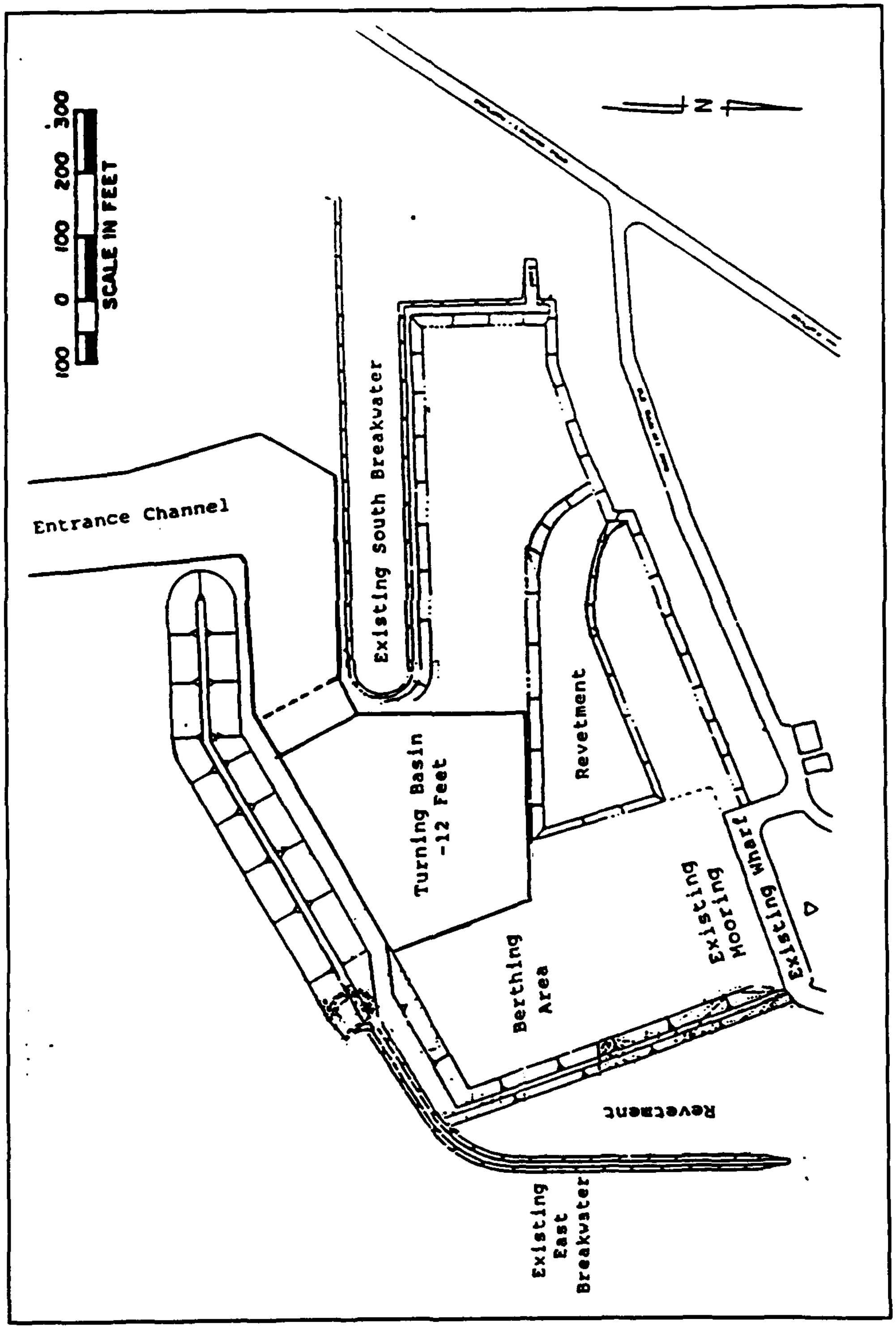

Figure 5. Proposed Plan 3

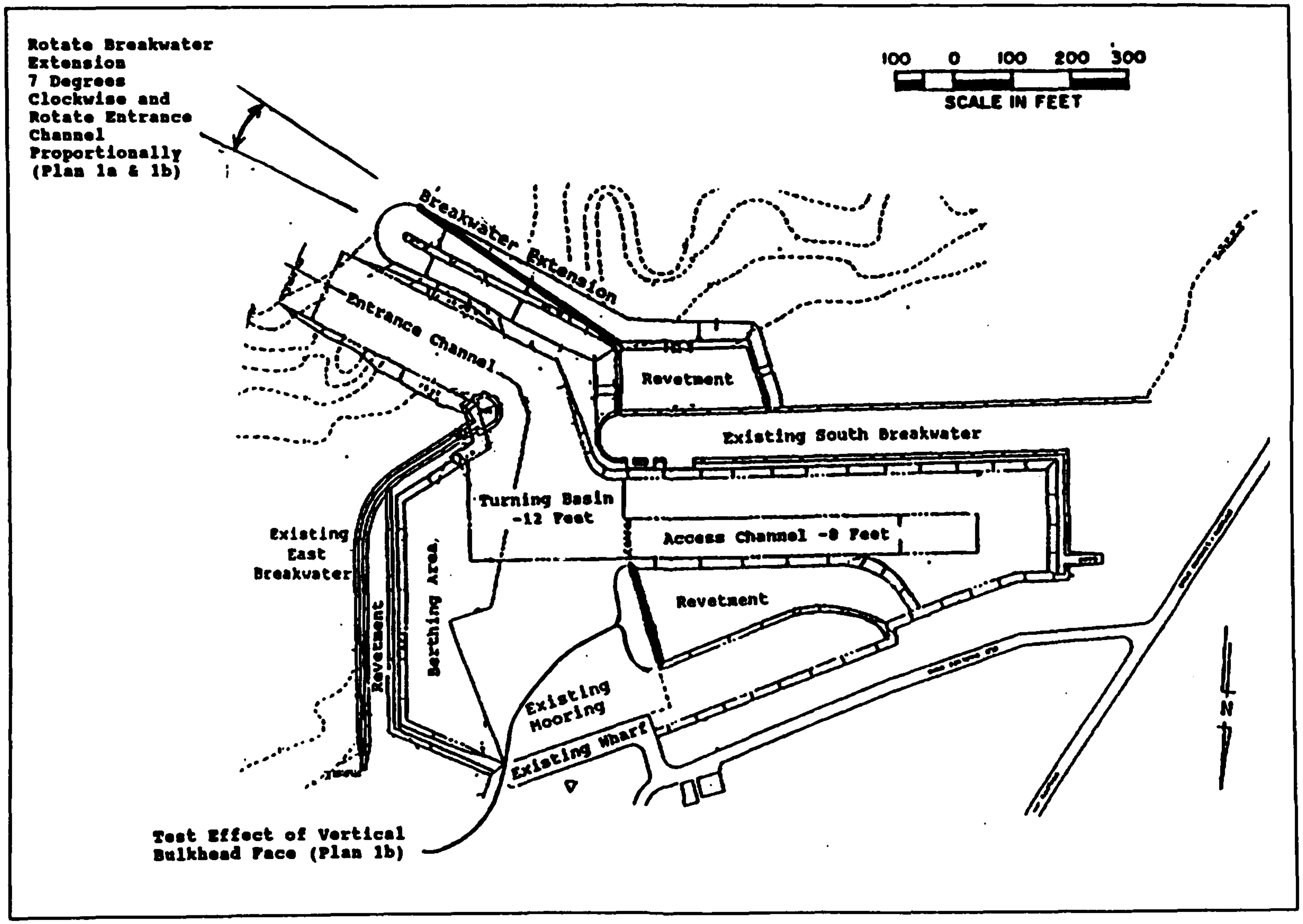

Figure 6. Proposed Plan 1a and 1b

Modeling Approach

Both numerical and physical modeling were considered for this study. Physical modeling has the advantages of providing more complete, reliable results for this particular study and would allow more comprehensive optimization of the project design. However, since the proposed design plans are considerably different, the physical model would cost significantly more and take longer to complete than the numerical model approach. The assumptions inherent in the numerical modeling approach are as follows:

No wave transmission or overtopping of structures.
Structure crest elevations will not be tested or optimized.
No wave-wave or wave-current interaction.
No wave breaking effects.
Diffraction around the structure ends will be represented by diffraction around a blunt vertical wall with a specified reflection coefficient.

Within limits of the assumptions, the numerical modeling approach can be expected to give a reasonable assessment of the proposed plans. This approach was selected because POD's allowable time and study funds were limited and design alternatives for this particular project were extensive. The procedure of this study is described in the following paragraphs.

The deepwater wave conditions for the southwest coast of the island of Maui were established from the Monitoring Completed Coastal Projects (MCCP) (US Army Corps of Engineers (USACE) 1987) measurements taken at Barbers Point Harbor, Oahu, HI. The percent occurrences of the deepwater conditions were calculated to later determine the percent occurrence of the wave heights inside the harbor. The method to establish the deepwater conditions is presented in Chapter 2 of this report, "Deepwater Wave Conditions."

The deepwater waves were transformed to the Maalaea Harbor vicinity through application of the SHALWV numerical model (Hughes and Jensen 1986). SHALWV simulates growth, decay, propagation, shoaling, refraction, and sheltering of a directional wave spectrum over arbitrary bathymetry. The SHALWV model was chosen due to its ability to include effects pertinent to this study such as: (a) simulation over an extensive area, (b) large depth gradients along the grid boundaries, (c) input along two grid boundaries, (d) wave refraction and diffraction around islands, and (e) the ability to model refined areas through subgrids. The SHALWV model is presented in Chapter 3 of this report, "Wave Transformation Modeling."

The resulting wave conditions of SHALWV were then used as input to HARBD to determine the wave response inside the harbor. HARBD is a steady state finite element model that calculates linear wave oscillations in harbors of arbitrary configuration and variable bathymetry. The effects of bottom friction and boundary absorption (reflection) are included. Through application of HARBD, the resulting wave heights in the harbor entrance and

access channels, turning basin, and berthing areas were determined and the percent occurrence of those conditions were calculated using the results of both the SHALWV and HARBD models. The HARBD model and details and results of the procedures are presented in Chapter 4 of this report, "Wave Response Modeling."

2 Deepwater Wave Conditions

Maalaea small boat harbor is affected primarily by wave conditions resulting from southern swell and "Kona", or low pressure systems, storm waves arriving from south or south-southwest. Sources of wave information for the Hawaiian Islands and particularly for use at the Maalaea Harbor vicinity are extremely limited.

Possible sources of wave information in the Hawaiian Islands include (Figure 7): the Wave Information Studies (WIS) deepwater hindcasts for the Pacific coast which include seven stations around the Hawaiian Islands (Corson, et al. 1986); the deepwater buoy, Station 51001 (Gilhousen, et al. 1986), operated by the National Oceanic and Atmospheric Administration's National Data Buoy Center (NDBC); the Summary of Synoptic Meteorological Observations (U.S. Naval Weather Service Command 1976) climatological summaries of shipboard wave observations; and the Monitoring Completed Coastal Projects (MCCP) Program of the US Army Corps of Engineers (USACE 1987) slope array at Barbers Point, Oahu.

Of the available data sources in the Hawaiian Islands, the wave measurements from the MCCP slope array at Barbers Point, Oahu, are the only directional data that have exposures representative of the coast relevant to Maalaea. Although Barbers Point is on a different island than Maalaea, the coastline orientation and southern exposure are similar at the two sites.

Deepwater Wave Climate

Offshore wave climate at the Maalaea harbor site was estimated using the MCCP Barbers Point slope array measurements. Although data sources are limited, the percent occurrence of significant wave height, peak spectral period, and direction are adequately represented in the Barbers Point data. These data include effects of southern swell, which is an important factor relevant to the Maalaea harbor site.

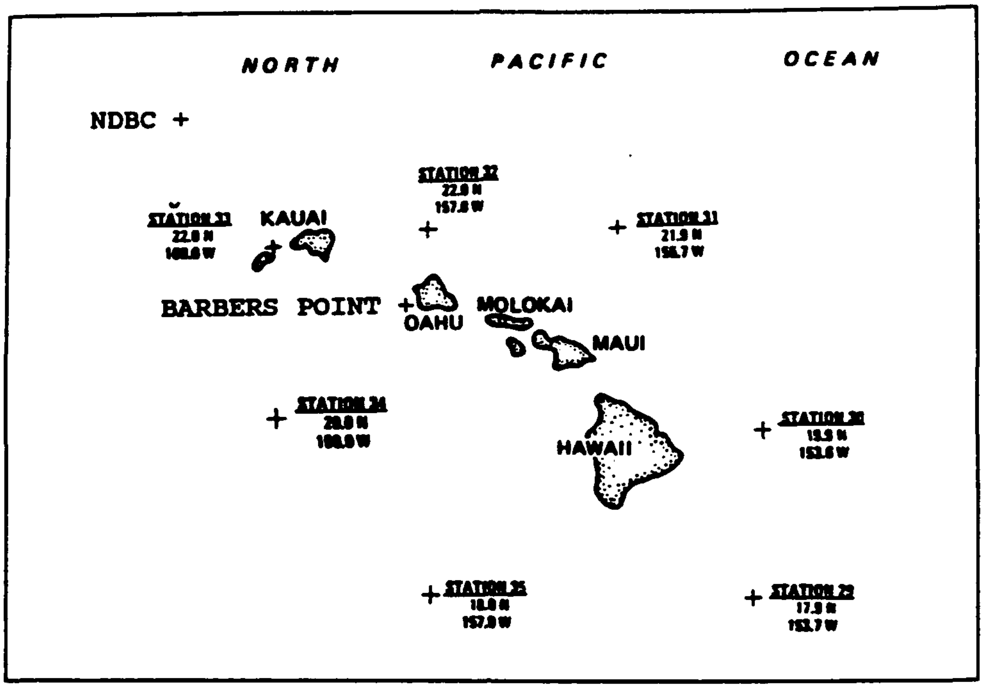

Figure 7. Sources of wave information in the Hawaiian Islands

Maalaea harbor is exposed to a sector of wave angles from about the 135.0- to 270.0-deg azimuth. MCCP measurements within this sector were taken as part of the deepwater climate at Maalaea. Measurements outside this sector were not used because the harbor is sheltered by land from those directions.

The MCCP Barbers Point measurements represent a general wave climate for a southwest-facing coast. Therefore, measurements taken during various intervals over the period from July 1986 through August 1990 were compiled to obtain a data set representative of one complete year. The measurements were then "unrefracted" from 28 ft to an approximate 1,300-ft depth to transfer the data set to an appropriate location fronting Maalaea. This process was accomplished through application of an Automated Coastal Engineering System (ACES) code which implements Snell's Law. Bottom contours were assumed straight and parallel. The percent occurrences from each direction in the exposed sector were then compiled and are given in Appendix A and summarized by direction in Table 1 at the end of the text of this report. The compiled percent occurrence of height, period, and direction are considered as the best possible representation of the deepwater wave climate for Maalaea Harbor. The percent occurrence of waves corresponding to Table 1 is shown in Figure 8.

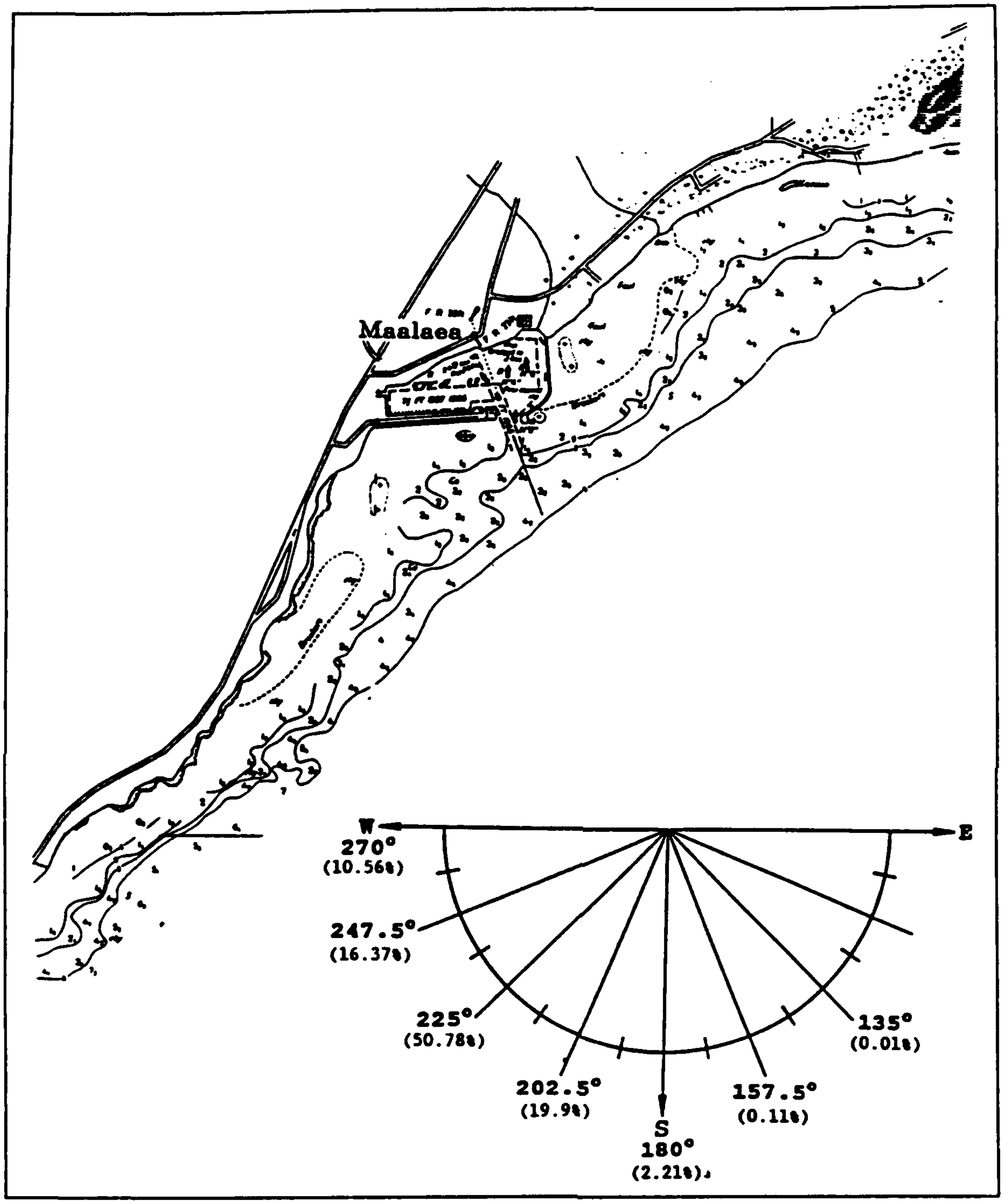

Figure 8. Percent occurrence of deepwater wave conditions by direction

3 Wave Transformation Modeling

Wave Transformation Model

Once the deepwater wave conditions are established, it is necessary to transform the waves shoreward to the Maalaea vicinity. This was accomplished using the numerical wave model SHALWV (Jensen, Vincent, and Abel 1987). SHALWV numerically simulates growth, decay, propagation, shoaling, refraction, and sheltering of a directional wave spectrum over arbitrary bathymetry. The modeled spectra are represented as fully two-dimensional spectra in discrete frequency and direction bands. The model is time-dependent and is most often used to simulate time-varying wave and wind conditions. SHALWV was chosen to transform waves to the Maalaea vicinity due to the sizable extent of the grid required to include the island of Kahoolawe. For this application, winds are not used; therefore, no wave growth occurs and wave input is held constant for each wave condition. The fetch of the modeled area is approximately 20 miles, therefore the effect of local winds is limited to higher frequencies. Although some differences in the distribution of wave energy in frequency and direction can be expected with the introduction of local winds, only extreme conditions will contribute significantly. Holding the wave conditions constant, in this case for 5 hr, neglects changes in regional winds and waves on a smaller time scale. This is a limitation of the measured data, which was collected in 6-hr increments.

The model is based on the solution of the inhomogeneous energy balance equation solved with finite-difference methods using square grid cells to describe the bathymetry and wind field. The field equation represents wind and wave growth, refraction, shoaling, nonlinear wave-wave interactions, high frequency energy dissipation, wave bottom interactions, and decomposition of the energy into wind-sea and swell wave components. The maximum time-step interval is determined from the following Courant number stability criterion which is based on grid size and water depth:

$$\frac{\Delta L}{\Delta t} > C_g(f^*)$$

where

ΔL = length of grid cell
Δt = computational time step
C_g = group velocity associated with lowest frequency at the deepest grid point
f^* = lowest spectral frequency

The Courant number criterion insures that wave energy does not propagate more than one grid cell during a time step (Hughes and Jensen 1986).

Wave Transformation Simulation

The SHALWV model uses a rectangular, uniformly spaced, finite difference grid that extends over the general area of interest. If necessary, the model allows additional subgrids that are used to resolve complex bathymetry in areas of interest. The main grid used in this study, shown in Figure 9, has 50 cells alongshore (positive x-axis directed east) and 42 cells across-shore (positive y-axis directed north). The grid has square cells of about 3,000 ft in the x and y directions. This grid covered the region of interest including Maalaea Bay and important sheltering features such as the island of Kahoolawe and McGregor Point. Waves were input along the x or y axis depending on the direction being modeled.

In order to resolve the bathymetry near Maalaea Harbor, a higher resolution subgrid of Maalaea Bay was included in the modeling effort. The extent of the subgrid is outlined in Figure 9. The subgrid consists of 35 alongshore and 31 across-shore square grid cells with about 750-ft sides. The resolution of the subgrid is approximately four times greater than the main grid. Wave output at the interface between the subgrid and the HARBD outer boundary were used as input to HARBD.

SHALWV transformation estimates were performed from a depth of approximately 1,300 ft at the offshore boundary to approximately 30 ft at the HARBD outer boundary (Maalaea harbor). Representative period-direction combinations were selected from the modified slope array data for input to SHALWV. Direction bands modeled were 22.5 deg and centered about the 135.0-, 157.5-, 180.0-, 202.5-, 225.0-, 247.5-, and 270.0-deg azimuth, as shown in Figure 9. Peak periods ranged from 9 to 20 sec and selected wave heights ranged from 3 to 8 ft based on shoaling estimates which would exceed the maximum 1- and 2-ft wave height criterion discussed in Chapter 4.

The wave conditions input to SHALWV and the corresponding transformed wave height and direction are given in Table 2 at the end of this text. Figures 10 through 16 are plots of wave direction vectors that show representative wave refraction from the SHALWV main grid input boundary, (x or y axis), to the subgrid boundary in the Maalaea Harbor vicinity. Each figure shows resulting wave direction vectors from input conditions of an 8-ft wave height,

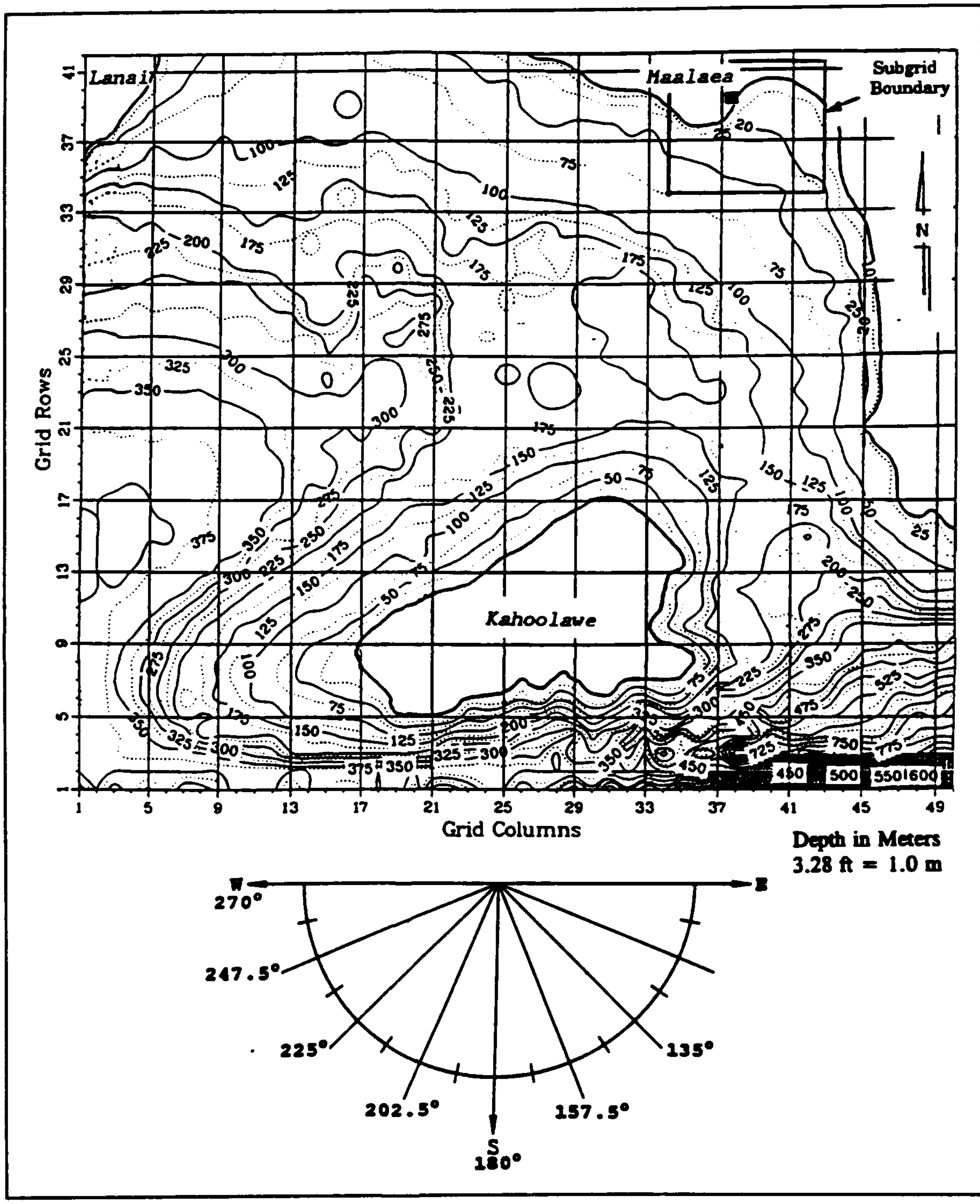

Figure 9. Maalaea SHALWV grid and bathymetry

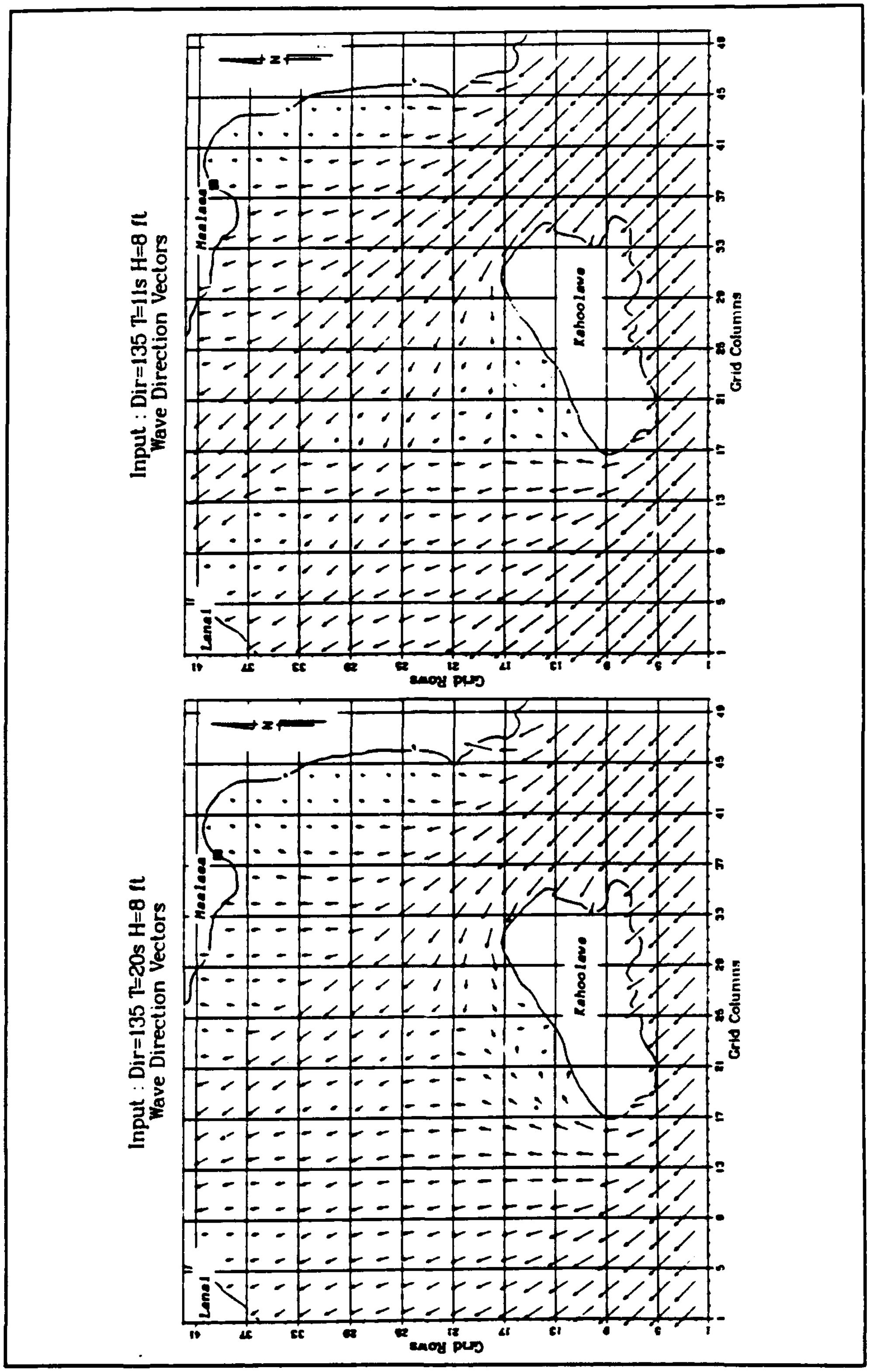

Figure 10. Wave direction vectors for 135.0 deg

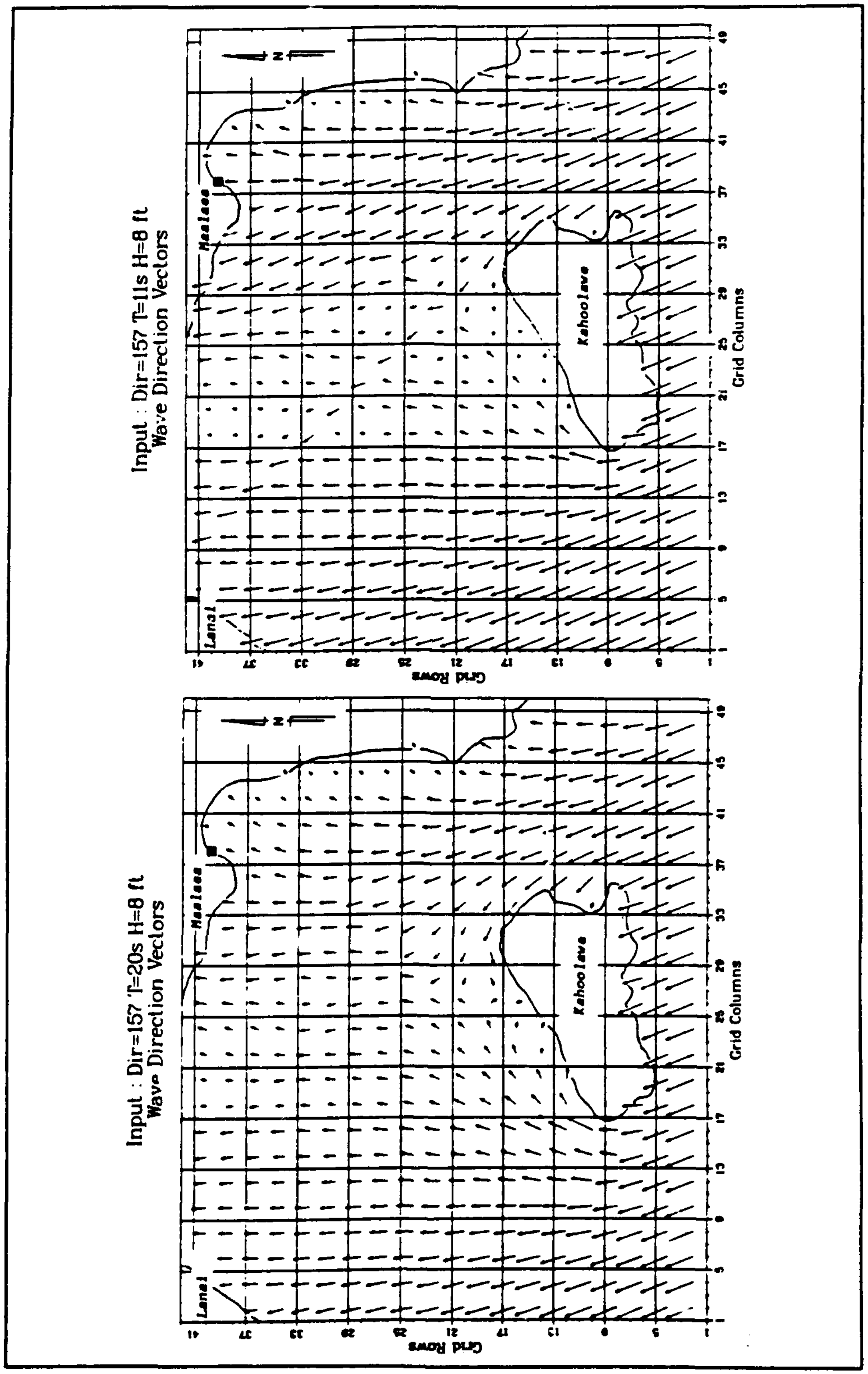

Figure 11. Wave direction vectors for 157.5 deg

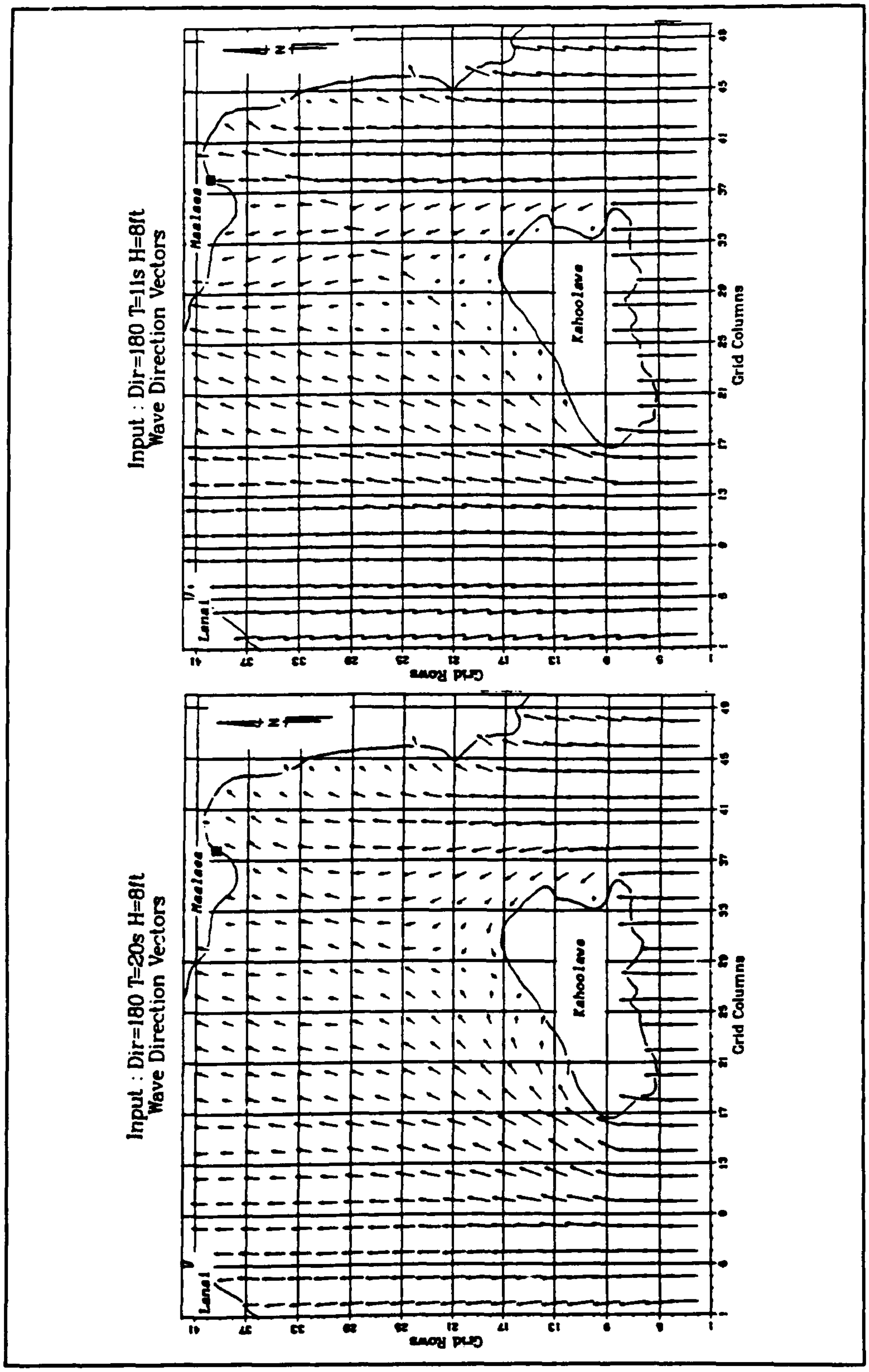

Figure 12. Wave direction vectors for 180.0 deg

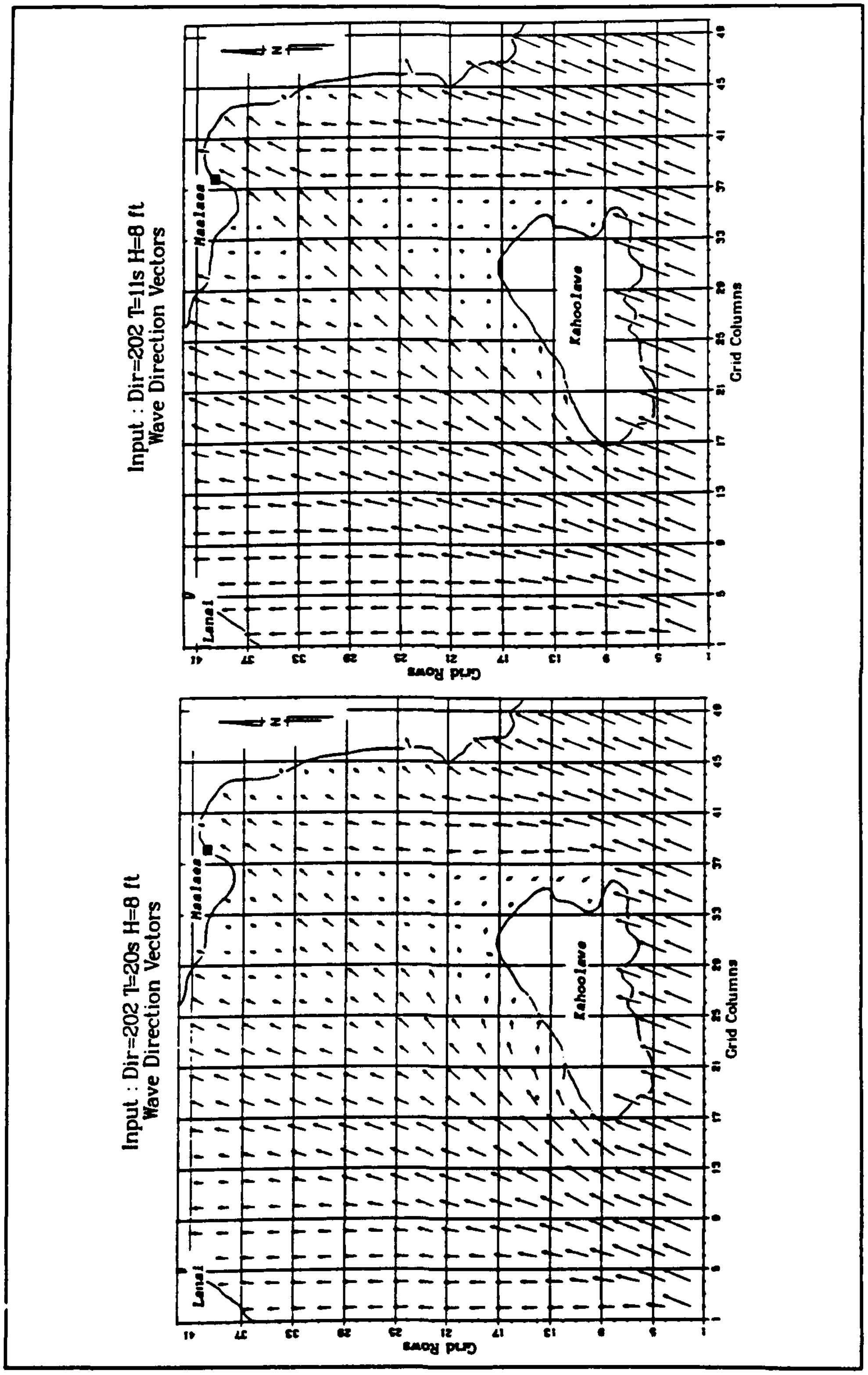

Figure 13. Wave direction vectors for 202.5 deg

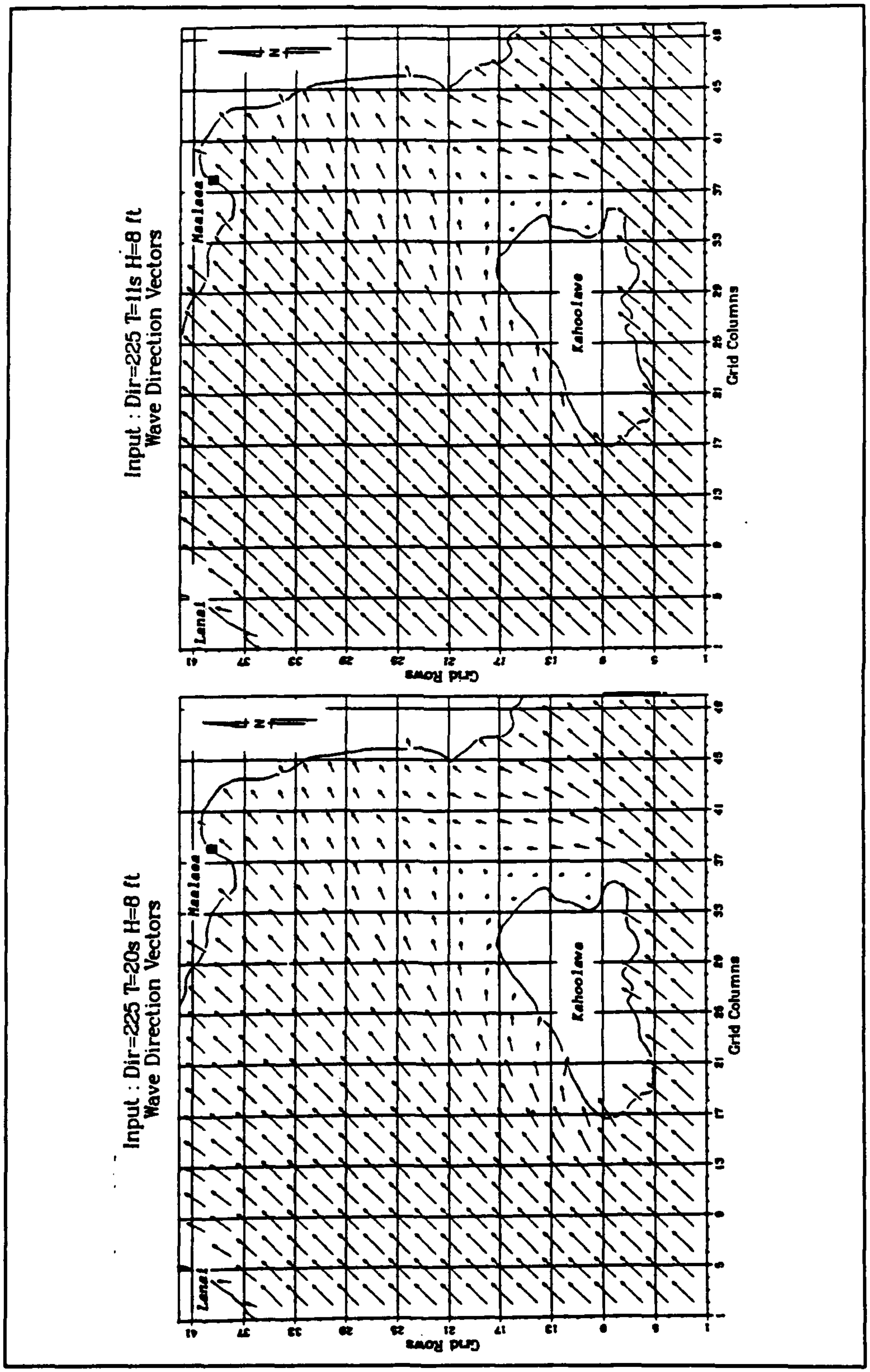

Figure 14. Wave direction vectors for 225.0 deg

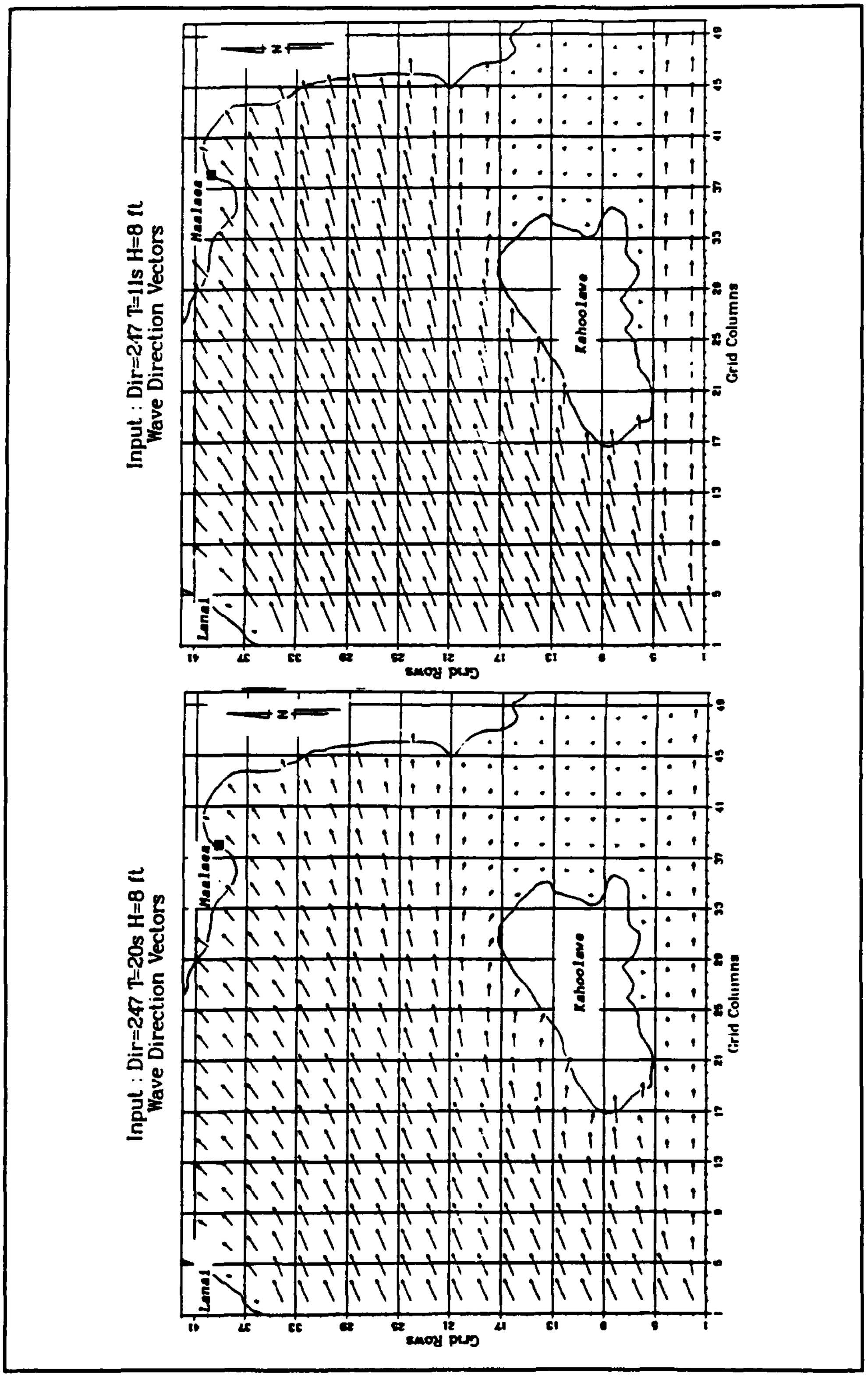

Figure 15. Wave direction vectors for 247.5 deg

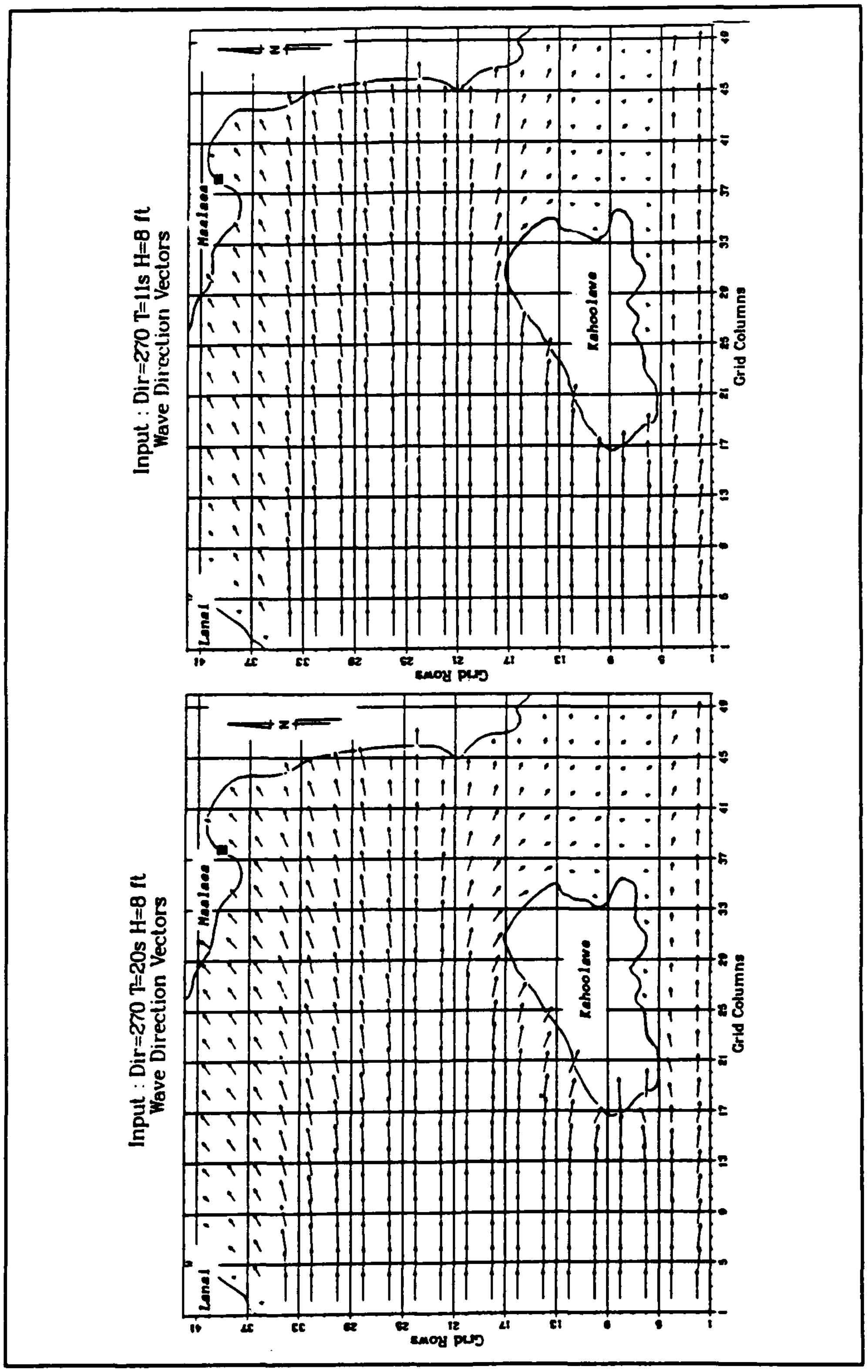

Figure 16. Wave direction vectors for 270.0 deg

an 11- and 20-sec wave period, and wave directions ranging from the 135.0- to 270.0-deg azimuth. The length and direction of the vectors represent the relative wave height and direction, respectively, for each grid point.

These plots show that waves coming from 247.5, 225.0, 202.5, and 180.0 deg produce the most wave energy at the Maalaea Harbor vicinity. Also, the shorter wave periods (11 sec) result in a higher percentage of energy reaching the harbor area than the longer period (20-sec) waves. Waves coming from 247.5 and 225.0 deg travel in nearly straight line paths to the harbor area, resulting in a shoaling dominant transformation process. Waves from 202.5 deg begin refracting toward the island of Kahoolawe on the east and west sides, which results in wave refraction focusing toward the harbor vicinity. Note that the effects of wave diffraction around the island of Kahoolawe are not included in the simulation. These effects do not significantly affect the wave energy reaching the harbor area for wave periods of 20 sec or less, since the distance between the island and the harbor area (12.5 miles) is much greater than 20 wavelengths (7.8 miles for a 20-sec wave). Waves coming from 180.0 deg travel through Alalakeiki Channel and are parallel to the bottom contours in Maalaea Bay. This results in another direct approach of wave energy into the harbor vicinity.

Given the percent occurrence of waves from the directions between 135.0 and 270.0 deg, (Figure 8), the most significant wave directions are 247.5 (16.37 percent), 225.0 (50.78 percent), and 202.5 (19.9 percent) deg. The percent occurrence of waves coming from 180.0 deg is 2.2 percent, and from 157.5 and 135.0 deg is less than 1 percent. Therefore, the frequency of waves affecting the harbor from these directions will be minimal.

4 Harbor Wave Response Modeling

Harbor Wave Response Model

The numerical model HARBD (Chen and Houston 1987) was used to simulate the wave response at Maalaea small boat harbor, Maui, Hawaii. HARBD is a steady state hybrid finite element model that calculates linear wave oscillations in harbors of arbitrary configuration and variable bathymetry. The model is advantageous over other numerical harbor models since bottom friction and boundary reflection are included. The bottom friction is assumed to be proportional to flow velocity with a phase difference. The boundary absorption is based on a formulation similar to that in the impedance condition in acoustics and is expressed in terms of wave number ($2\pi/L$ where L is the wavelength) and reflection coefficient of the boundary. The result is that HARBD predicts wave amplitudes that are more realistic than those from previous models (Chen and Houston 1987). HARBD was originally developed for harbor oscillations (long-period waves), and the general formulation was adapted for wind waves (short-period waves) by Houston (1981).

The model has been tested and compared with known analytical solutions for a number of cases and the results are excellent (Chen 1984, and Chen and Houston 1987). It has been applied in the design or modification of Agat Harbor, Guam (Farrar and Chen 1987); Kawaihae Harbor, Hawaii, Hawaii (Lillycrop, Bratos, and Thompson 1990); and Barbers Point Harbor, Oahu, Hawaii (Durham 1978). The model was instrumental in studying the effects of entrance channel dredging at Morro Bay Harbor, California (Kaihatu, Lillycrop, and Thompson 1989), and analyzing harbor resonance at Los Angeles-Long Beach Harbor California (Sargent 1989). The model was used to plan wave protection at Fisherman's Wharf, San Francisco, California (Bottin, Sargent, and Mize 1985); Green Harbor, Massachusetts (Weishar and Aubrey 1986); Los Angeles-Long Beach Harbor, California (Houston 1976); and to estimate the wave conditions in Indiana Harbor, Indiana during a study of sediment disposal alternatives (Clausner and Abel 1986). HARBD was compared to laboratory data collected from the physical model study of Barcelona Harbor, Buffalo, New York (Crawford and Chen 1988) with encouraging results. The predictions of HARBD are currently under further

comparison with prototype and physical model data collected from recent studies of Barbers Point Harbor, Oahu, Hawaii.

HARBD uses a hybrid element method in which a finite element solution in the interior region of the harbor is matched to an analytical solution in the exterior region. In the interior region, HARBD allows arbitrary bathymetry, (i.e., shallow, intermediate, and deepwater waves), variable configuration, and the effects of bottom friction and boundary reflection.

In model formulation for arbitrary depth water waves, the water domain is divided into near and semi-infinite far regions. The near region is bounded by an artificial 180 deg semi-circular boundary outside the harbor and includes the interior harbor and all marine structures and bathymetry of interest. The far region is an infinite semicircular ring shape bounded by the near region and the coastlines. The region extends to infinity in all horizontal directions. The semi-infinite far region is assumed to have a constant water depth and no bottom friction (Chen and Houston 1987). The finite near region, which contains the area of interest, is subdivided into a mesh of triangular shaped elements. The length of the sides of each element is determined from the desired grid resolution and design wave parameters. The water depth and bottom friction coefficient are specified for each element, and a reflection coefficient is assigned to each element on the solid boundaries. The model requires a wave period and direction as input. The solution consists of an amplification factor (i.e., the ratio of the wave height to the incident wave height) and a corresponding phase angle for the entire near region. The phase angle is of little importance to the present study.

The governing partial differential equation is derived through application of linear wave theory to the continuity and momentum equations. This also assumes all dependent variables are periodic in time with angular frequency ω. These steps yield the following generalized Helmholtz equation (Chen 1986) in which the velocity potential ϕ is solved:

$$\nabla(\lambda c c_g \nabla \phi) + \frac{c c_g}{c} \omega^2 \phi = 0 \qquad (2)$$

where

∇ = horizontal gradient operator
λ = complex bottom friction factor
c = wave phase velocity = (ω/κ)
c_g = wave group velocity = $[c/2\{1 + (2\kappa h/\sinh 2\kappa h)\}]$
κ = wave number, $(2\pi/L)$, where L = wavelength
ω = angular frequency
ϕ = velocity potential
h = water depth

The wave number is obtained from the dispersion relation.

$$\omega^2 = g\kappa \tanh(\kappa h) \tag{3}$$

where g = acceleration due to gravity

The complex bottom friction factor λ is assumed proportional to the maximum velocity at the bottom and is defined as:

$$\lambda = \frac{1}{1 + \dfrac{i\beta a_o}{h \sinh \kappa h} \exp(i\gamma)} \tag{4}$$

where

β = dimensionless bottom friction coefficient that varies spatially
a_o = incident wave amplitude
γ = phase shift between stress and flow velocity
i = $(-1)^{1/2}$

The effects of bottom friction do not necessarily need to be included in the general solution. This is accomplished by setting $\beta = 0$, which results in $\lambda = 1$, and Equation 1 reduces to an expression which excludes bottom friction.

For the absorptive boundary condition along the solid harbor boundaries, the model adopts the impedance condition used in acoustics in terms of the boundary reflection coefficient K_r expressed as:

$$\frac{\partial \phi}{\partial n} - \alpha \phi = 0 \tag{5}$$

with

$$\alpha = i\kappa \frac{1 - K_r}{1 + K_r} \tag{6}$$

where

α = dimensional coefficient related to the boundary reflection
n = unit-normal vector directed outward from the fluid domain

Similar to the friction coefficient, when $K_r = 1$, then $\alpha = 0$ and Equation 5 reduces to a zero velocity potential normal to the boundary (Sargent 1989). This infers a perfectly reflecting boundary condition.

A conventional finite element approximation is used in the near region, and an analytical solution with unknown coefficients is used to describe the semi-

infinite far region. Conditions in the near and far regions must be matched along the artificial semicircle boundary. This requirement is met by HARBD routines which automatically match the solutions using the stationarity of a functional, to a series of Hankel Functions which give the solution for the infinite region (Farrar and Chen 1987). The hybrid element numerical techniques used in the formulation are discussed in greater detail in Chen and Mei (1974).

The HARBD model is intended to simulate waves that can be adequately described by the mild slope equation (Equation 2). Model accuracy decreases as wave conditions approach those outside the validity of this governing equation. HARBD does not simulate nonlinear processes such as wave breaking, wave transformation and overtopping of structures, and wave current interaction; however, the model predicts wave heights accurately if these processes are not dominant. Since nonlinear processes naturally occur in the prototype, care and consideration of the effects must be taken in interpretation of results.

Finite Element Grids

Finite element grids generated for the Existing Plan and Plans 1, 2, and 3 are shown in Figures 17 through 20, respectively. The grid used for both Plans 1a and 1b is shown in Figure 21. All grids cover approximately the same interior harbor areas, however, coverage of the offshore area is variable. In order to model areas pertinent to each plan, the Existing and Plans 1, 1a, and 1b include the offshore area eastward, while Plans 2 and 3 include the offshore area westward. The radius of the semicircular boundary is approximately 800 ft for the existing and Plan 1, 1a, and 1b grids, and approximately 700 ft for the Plan 2 and 3 grids. The radial distance is designed to include the entrance channel and allow enough area to include possible modifications.

Total numbers of elements (triangles), nodes (triangular corners), and boundary elements are:

Existing:	7,146 elements, 3,752 nodes, 252 boundary elements
Plan 1:	6,765 elements, 3,613 nodes, 356 boundary elements
Plan 2:	7,866 elements, 4,176 nodes, 353 boundary elements
Plan 3:	7,911 elements, 4,215 nodes, 386 boundary elements
Plans 1a,1b:	6,810 elements, 3,636 nodes, 357 boundary elements

Each grid was designed with a grid resolution of approximately six elements per wavelength, based on an 8-sec wave period and a basin depth of 8 ft.

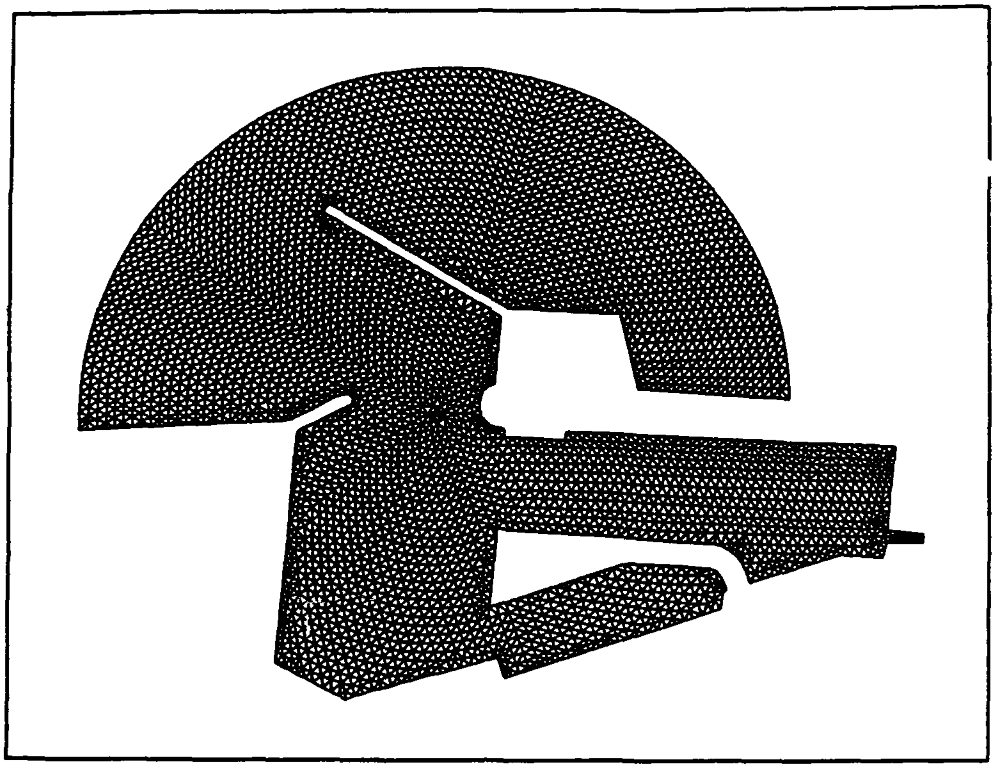

Figure 17. Finite element grid for Existing Plan

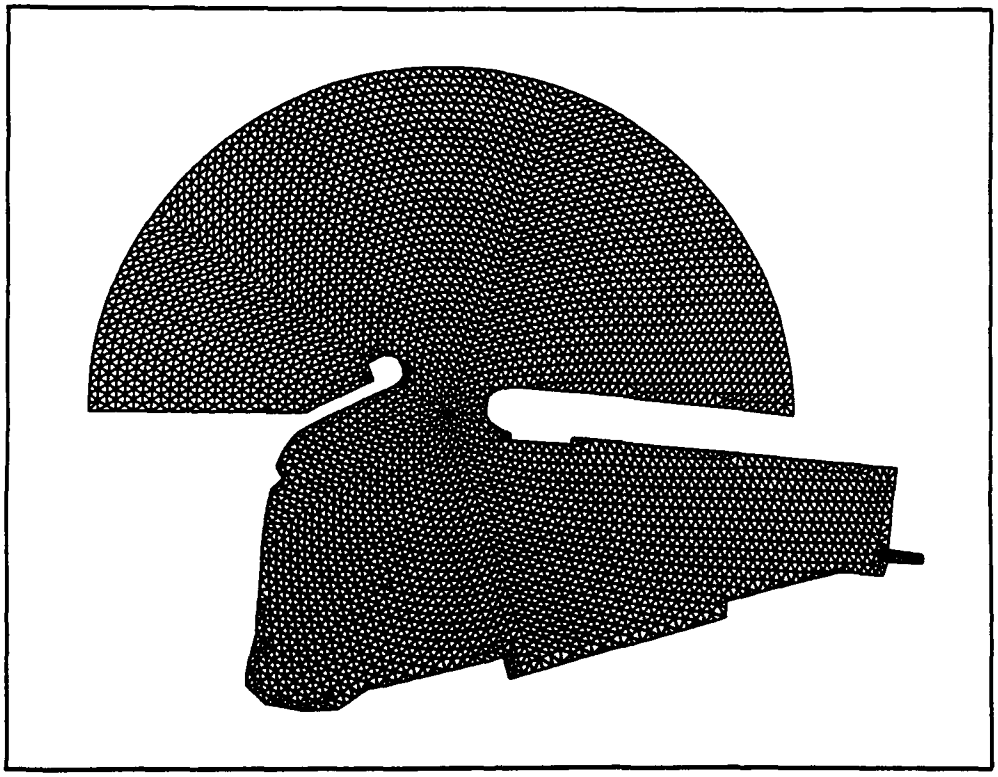

Figure 18. Finite element grid for Plan 1

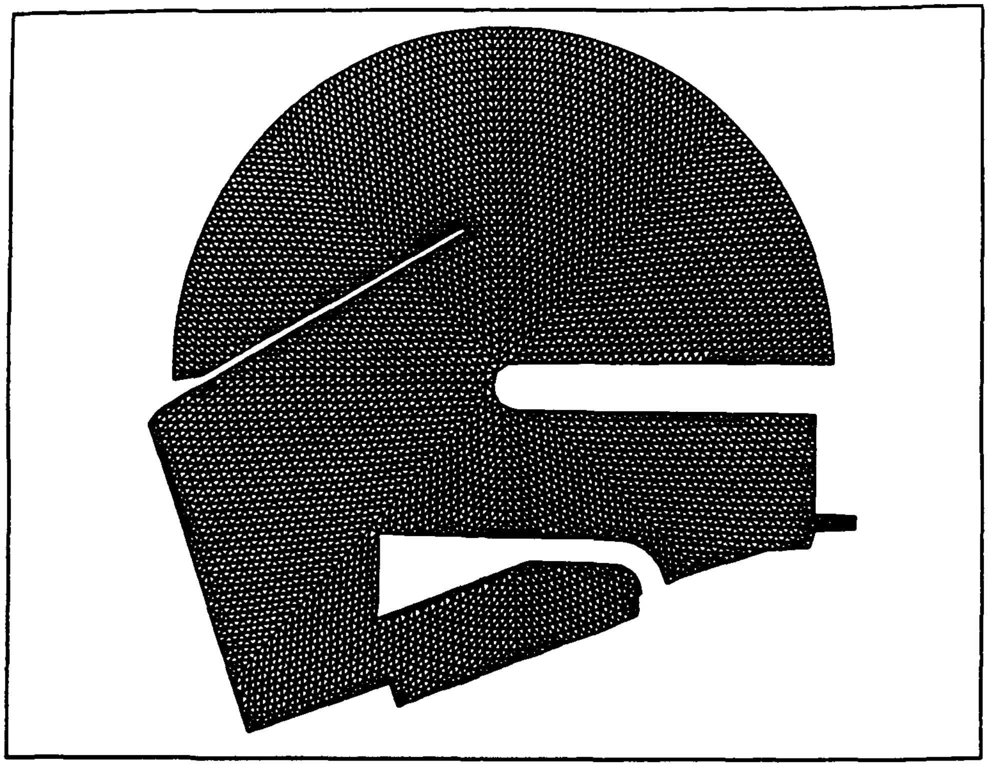

Figure 19. Finite element grid for Plan 2

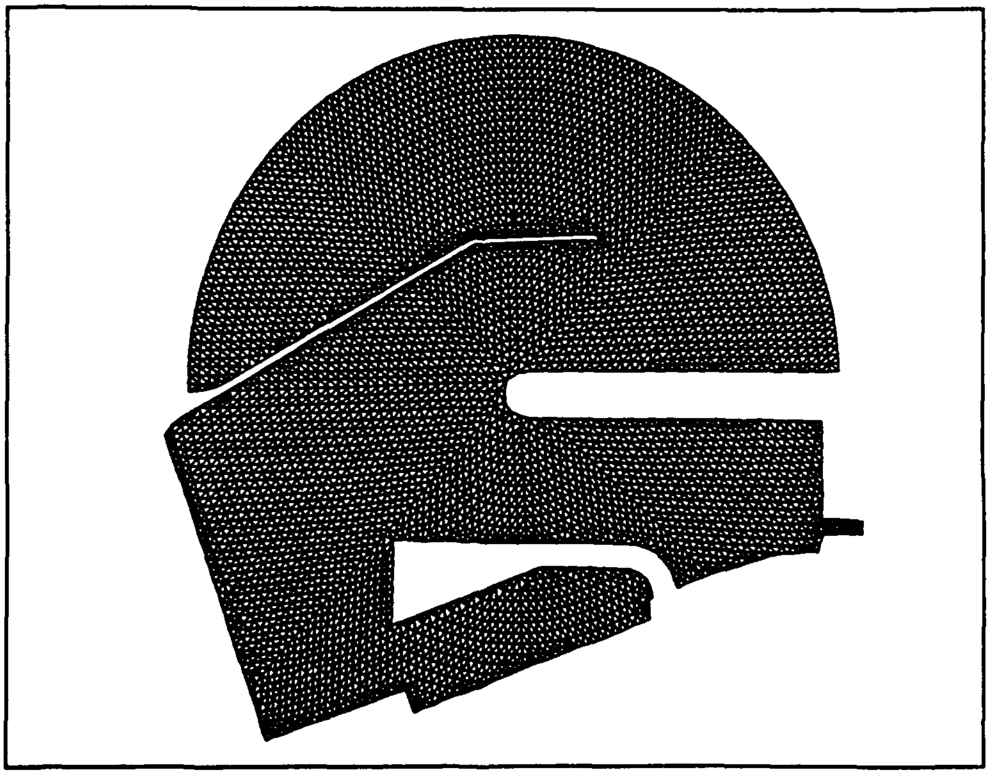

Figure 20. Finite element grid for Plan 3

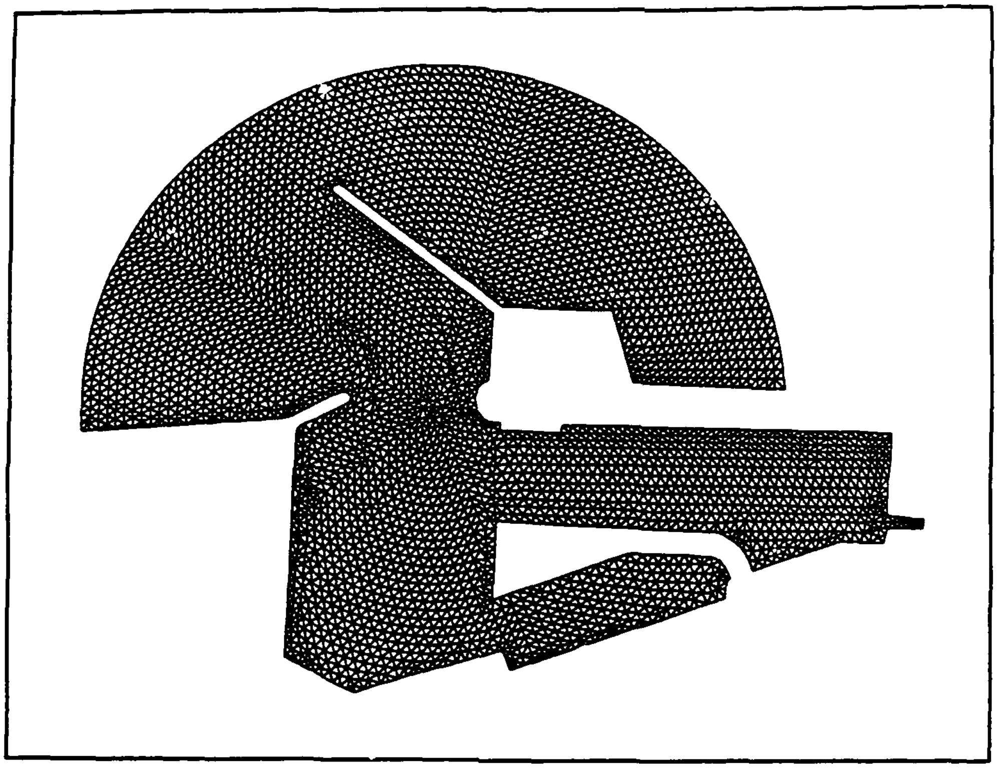

Figure 21. Finite element grid for Plans 1a and 1b

The grid bathymetry was obtained from POD hydrographic surveys taken in 1989. The design still-water level (swl) was used for all tests. Boundary reflection coefficients of the interior harbor walls were calculated using methods in the *Shore Protection Manual* (SPM 1984), and were refined upon recommendation from POD. The assigned reflection coefficients for the existing structures were 0.40 for the 1:2-sloped seaward and harbor sides of the south breakwater and along the west and north walls of the harbor basin, 1.0 for the paved wharf, and 0.35 for the 1:2-sloped seaward and harbor sides of the east breakwaters. For Plan 1, the reflection coefficients for the structural improvements were 0.25 for the 1:2-sloped south breakwater extension and seaward side revetment and 0.35 for the 1:1.5-sloped interior revetments along the existing east breakwater and at the center of the harbor basin. For the structural improvements of Plan 2, the reflection coefficients were 0.25 for the 1:2-sloped east breakwater extension and 0.35 for the 1:1.5-sloped interior revetments as in Plan 1. The additional 250-ft-long 1:2-sloped east breakwater extension in Plan 3 was assigned a reflection coefficient of 0.25. Reflection coefficients in Plan 1a were the same as in Plan 1. Plan 1b differed from Plan 1a in that the reflection coefficient along the east face of the center mole was set to 1.00. The open boundary along the east diameter of the semicircle was fully transmissive. The bottom friction factor β was set at 0.05 since the entire bottom was sandy (Kaihatu, Lillycrop, and Thompson 1989).

The grids for this study were generated through application of automated finite element grid generation software developed at the Oregon Graduate

Institute (OGI) by Dr. Antonio M. Baptista and Mr. Paul J. Turner. This procedure for automated HARBD grid generation was an original WES application.

Harbor Wave Response Simulation

To establish the wave climate incident to Maalaea harbor, a total of 187 deepwater wave height, period, and direction combinations were input to the SHALWV model and transformed to the Maalaea harbor vicinity. The selected SHALWV output locations and their relation to Maalaea Harbor were given previously in Chapter 3 of this report. Deepwater wave characteristics and the resulting transformed wave conditions are given in Table 2. To determine wave heights throughout the harbor, the resulting SHALWV wave heights were multiplied with the HARBD amplification factors corresponding to each deepwater condition. The 187 wave height, period, and direction combinations were tested for the Existing Plan and Plans 1, 2, 3, 1a, and 1b. All simulations were run on the WES CRAY Y-MP supercomputing facilities.

Output "basins" were selected for each plan tested to determine wave response throughout the harbor. A basin is an area consisting of a specified number of elements from which the mean value of the results of those elements is calculated. Sixteen output basin locations were selected for the Existing Plan, 23 for Plans 1, 2, 1a, and 1b, and 24 for Plan 3. The locations were selected in areas of interest for safe navigation and mooring by CERC and POD, and are shown for each plan tested in Figures 22 through 25. For the Existing and Plans 1, 2, and 3, basins 1 through 3, 1 through 5, 1 through 6, and 2 through 7, respectively, are located throughout the harbor entrance and access channels and turning basin with a 2-ft maximum wave height criterion. Basins 3 through 16, 6 through 23, 7 through 23, and 8 through 24, respectively, are located in the harbor berthing areas with a 1 ft maximum wave height criterion. Basin locations and numbers in Plans 1a and 1b are identical to those in Plan 1. The resulting HARBD amplification factors at these basins for each deepwater wave condition were saved and tabulated for each plan (Tables 3 through 44).

The percent occurrence of wave heights exceeding 1 ft in the berthing areas and 2 ft in the entrance and access channels and turning basin were calculated for the Existing and Plans 1, 2, 3, 1a, and 1b. The procedure to calculate the percent occurrence of wave heights exceeding the 1-ft maximum criterion is as follows. The largest HARBD amplification factor of the basins located in the 1-ft maximum wave height criterion areas (berthing areas), was selected for each deepwater wave condition. The selected HARBD amplification factors were then multiplied by the transformed wave heights from SHALWV corresponding to each deepwater wave period and direction with a wave height of 3 ft. If the resulting SHALWV-HARBD wave height does not exceed 1 ft, the largest HARBD amplification was then multiplied by the transformed SHALWV wave height corresponding to the deepwater wave conditions with a wave height of 4 ft. The iterative process continued until the resulting wave height exceeded the maximum 1 ft wave height criterion or

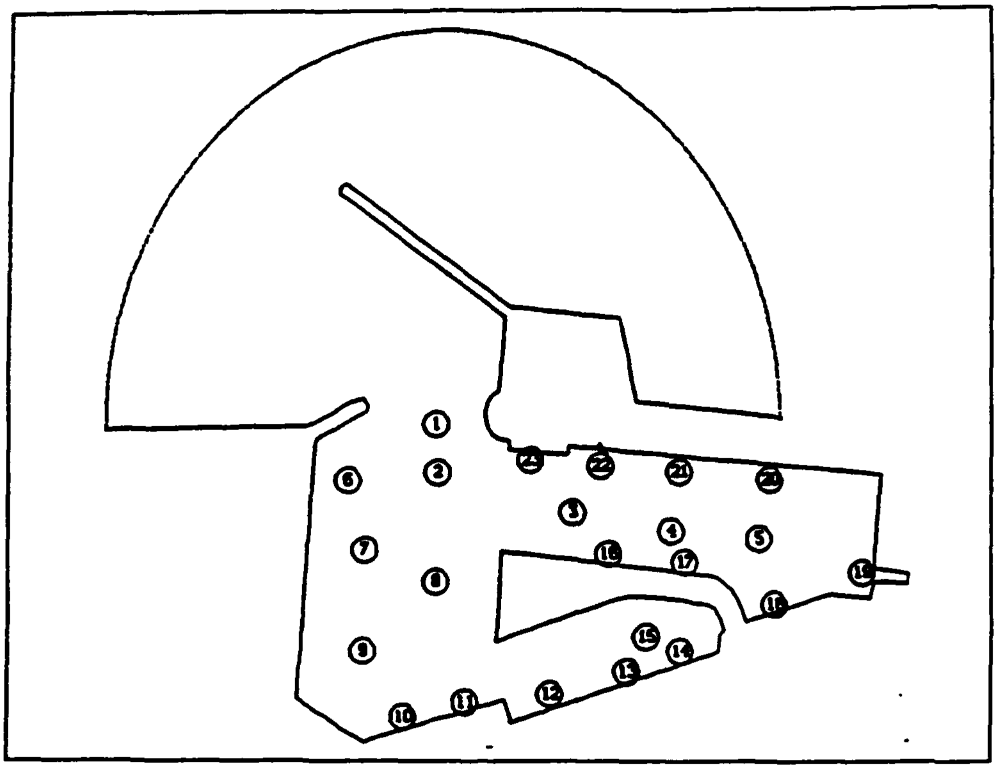

Figure 22. Output basin locations for Existing Plan

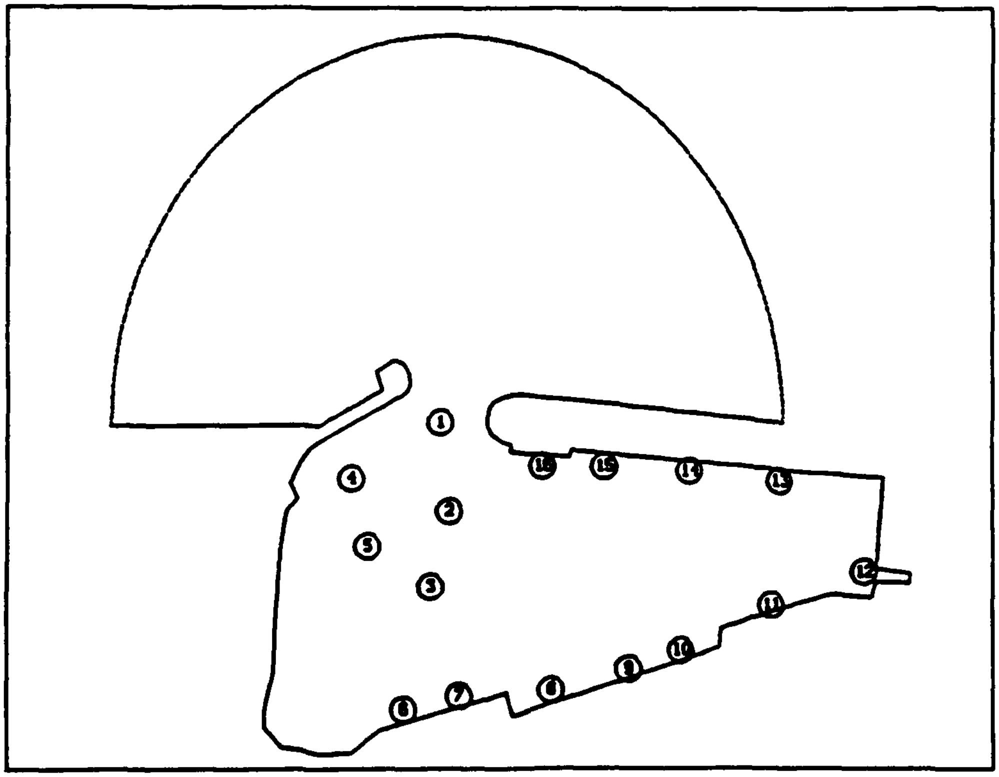

Figure 23. Output basin locations for Plans 1, 1a, and 1b

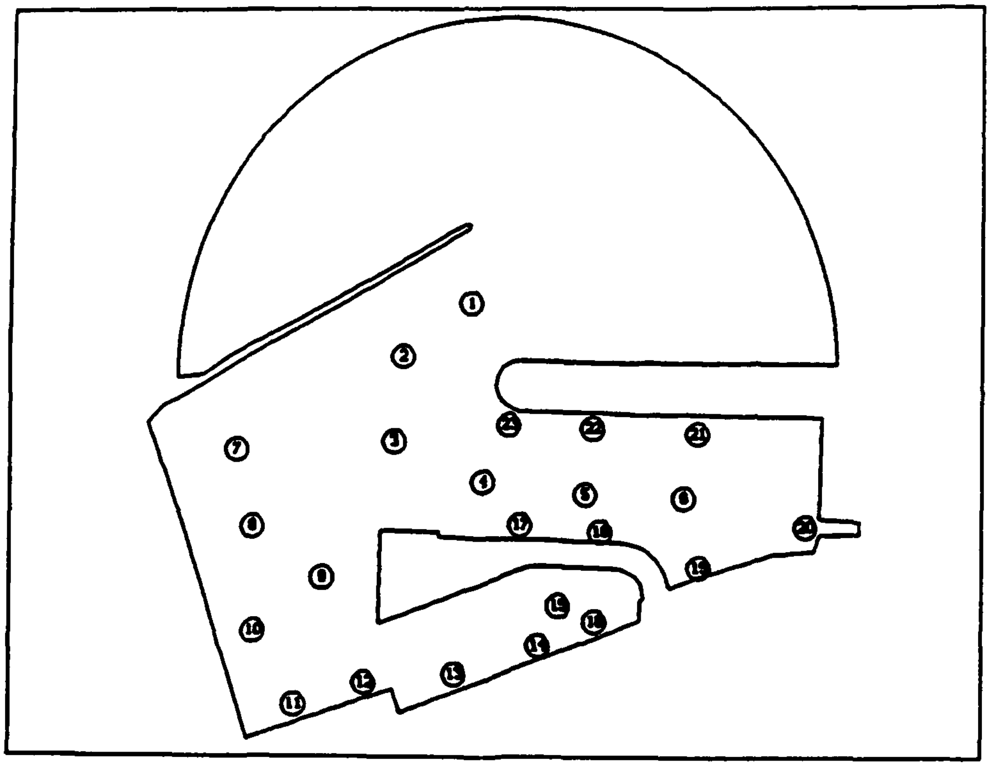

Figure 24. Output basin locations for Plan 2

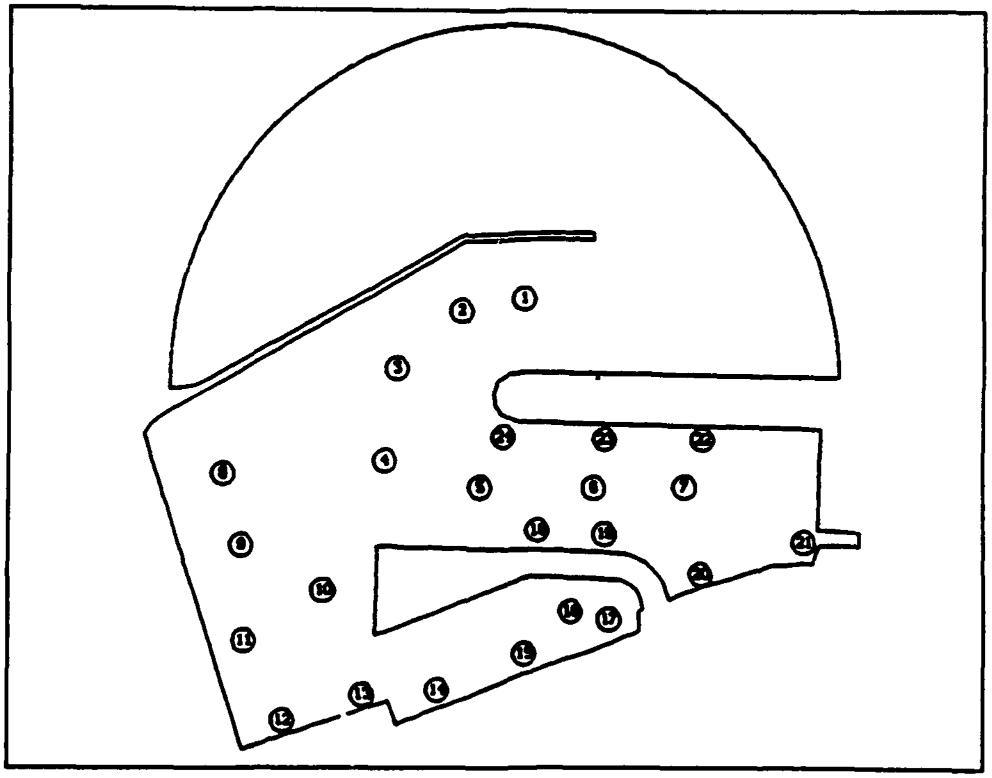

Figure 25. Output basin locations for Plan 3

the deepwater wave height exceeded 9 ft. The percent occurrence of wave heights exceeding 9 ft was included in all tabulations since the incremental deepwater wave heights greater than 9 ft could not be defined. The percent occurrence of those resulting wave heights which exceeded 1 ft were then tabulated from the percent occurrence tables for the deepwater wave conditions. The same procedure was used to calculate the percent occurrence of wave heights exceeding the maximum 2-ft criterion for those basins located in the harbor entrance and access channels and turning basin. As expected, wave heights from the Existing Plan are largest. Wave heights from Plan 2 exceed those of Plans 1 and 3, and wave heights from Plan 3 are lowest overall.

The above-mentioned procedure can be followed to calculate the resulting HARBD-SHALWV wave height at a specific output location of the Existing or Plans 1, 2, 3, 1a, and 1b for a specified deepwater wave period, direction, and height. Tabulations of these results are not included in the text due to the substantial amount of data involved.

Tables 45 through 50 are tabulations of the HARBD-SHALWV wave heights initially exceeding the HQUSACE criterion for each deepwater wave direction. The deepwater wave period, exceeding wave height, deepwater wave height, HARBD amplification factor, SHALWV wave height, and basin in which they occurred are given for the 1- and 2-ft maximum criteria for the Existing and Plans 1, 2, 3, 1a, and 1b. For the Existing Plan, Table 45 shows that the wave heights initially exceeding the maximum 1 ft criterion berthing areas (basins 3 through 16) were caused by a 9-sec wave from 247.5 deg, a 13-sec wave from directions of 157.5 and 225.0 deg, a 15-sec wave from 202.5 deg, and a 17-sec wave from 180.0 deg. The exceeding wave heights from directions of 157.5, 180.0, 202.5, and 247.5 deg occurred in basin 4 and the wave from 225.0 deg occurred in basin 9. Referring to Figure 22, basin 4 is located just inside the entrance toward the eastern side of the harbor and basin 9 is located along the northern wall. Wave heights exceeding the 2-ft maximum criterion turning basin and entrance channel (basins 1 and 2) resulted from a 9-sec wave from directions of 225.0 and 247.5 deg, a 15-sec wave from 180.0 deg, and a 17-sec wave from 202.5 deg. These waves occurred at the harbor entrance in basin 1.

In evaluating Table 46 for Plan 1, the wave heights initially exceeding the 1-ft criterion in the berthing areas (basins 6 through 23) are caused by a 13-sec wave from 180.0 deg and a 15-sec wave from 225.0 deg. The wave from 180.0 deg occurred in basin 11, located along the existing wharf, and the 225.0-deg wave occurred in basin 8, located east of the interior revetment. The maximum 2-ft wave height criterion was not exceeded for Plan 1.

Wave conditions initially exceeding the maximum 1-ft criterion berthing areas for Plan 2 (basins 7 through 23) include: an 11-sec wave from 157.5 deg, occurring along the south breakwater in basin 23; a 20-sec wave from 180.0 deg in basin 8; and a 20-sec wave from 202.5 deg and an 11-sec wave from 225.0 deg, both occurring in basin 7. Basins 7 and 8 are located near the east breakwater. Wave heights initially exceeding the 2-ft maximum criterion channels and turning basin include: an 11-sec wave from 157.5 deg;

a 20-sec wave from 180.0 deg and 202.5 deg; and a 9-sec wave from 225.0 deg. These waves all occurred in basin 1 located at the harbor entrance.

As shown in Table 48, none of the deepwater wave conditions resulted in wave heights exceeding the maximum 1- and 2-ft criteria for Plan 3, however, the percent occurrence of wave heights greater than 9 ft was included in the tabulations for this plan.

For Plan 1a, wave heights exceeded the 1-ft berthing area criterion for many of the shorter wave periods with directions from 180 deg to 247.5 deg (Table 49). In most cases, the exceedance occurred at basin 11, located along the existing wharf. The 9-sec waves caused exceedances at basins 6 and 8, located near the east breakwater. The 2-ft criterion was exceeded at basin 1 for 9 sec periods from 202.5 deg and 225.0 deg and for 11-sec periods from 225.0 deg.

The 1-ft criterion was exceeded for Plan 1b for many of the shorter periods with directions between 157.5 deg and 247.5 deg (Table 50). The exceedances generally occurred at basin 11, though basins 6 and 7 also appeared. The 2-ft criterion was exceeded at basin 1 for 9-sec waves from 202.5 deg and 225.0 deg and 11-sec waves from 225.0 deg.

The percent occurrence of wave heights exceeding the maximum 1- and 2-ft criteria more than approximately 10 percent of the time were calculated using the percent occurrence tables of deepwater conditions and HARBD-SHALWV wave height results for all plans. These results are given in Tables 51 through 62 and illustrated in Figures 26 through 31. Although wave breaking was not taken into account in Tables 51 through 62, the higher wave heights would most likely have broken over the reef, thus reducing wave heights in the harbor. In evaluating the resulting percent occurrence tables (Tables 51 through 62) and Figures 26 through 31, it is apparent that waves approaching from the southeast (135.0- to 157.0-deg) directions are insignificant in comparison to waves approaching from the south to west (180.0- to 270.0-deg) directions.

The percentage of wave heights exceeding the maximum 1 ft and 2 ft criteria for the Existing and Plans 1, 2, 3, 1a, and 1b are summarized in Table 63, along with the HQUSACE criteria. These values are conservative since they represent basins with the largest wave heights occurring in the harbor for each deepwater wave condition. The Existing Plan and Plans 2 and 1b allow one or both of the HQUSACE criteria of wave heights greater than 1 and 2 ft more than 10 percent of the time per year to be exceeded. However, Plans 1 and 1a, which include structural modification to the east, and Plan 3, which includes structural modification toward the west, satisfy the HQUSACE criteria for providing adequate protection inside the harbor. Although Plan 1a satisfies the 1 ft berthing area criterion, the results indicate that basin 11, along the existing wharf, may be marginally acceptable.

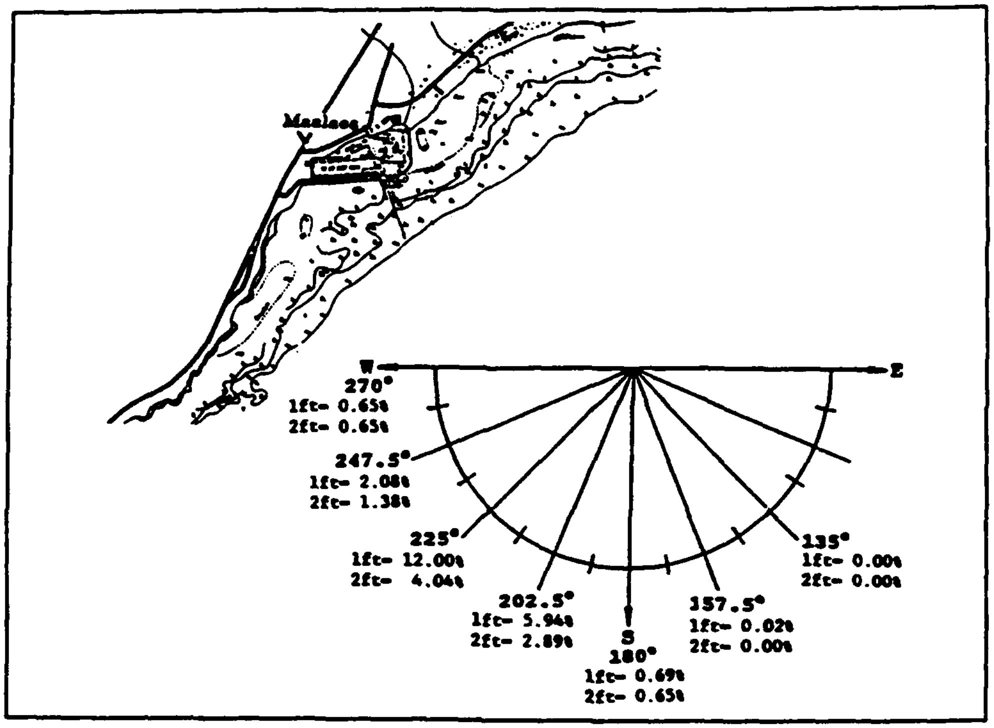

Figure 26. Existing Plan - Percent occurrence of wave heights exceeding 1- and 2-ft criteria

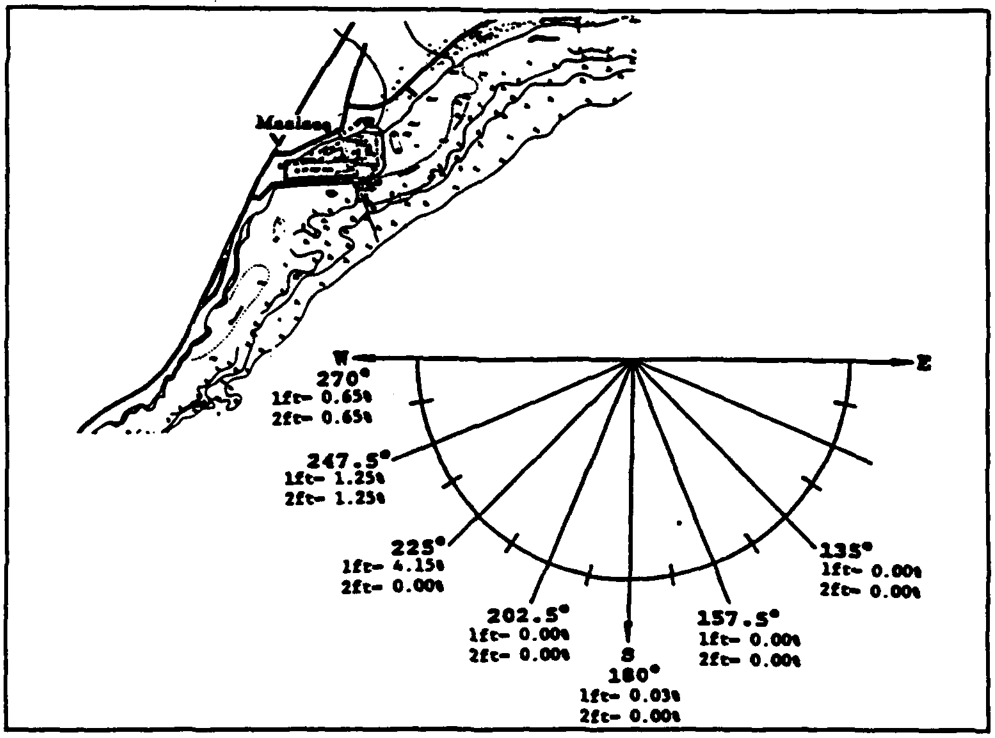

Figure 27. Plan 1 - Percent occurrence of wave heights exceeding 1- and 2-ft criteria

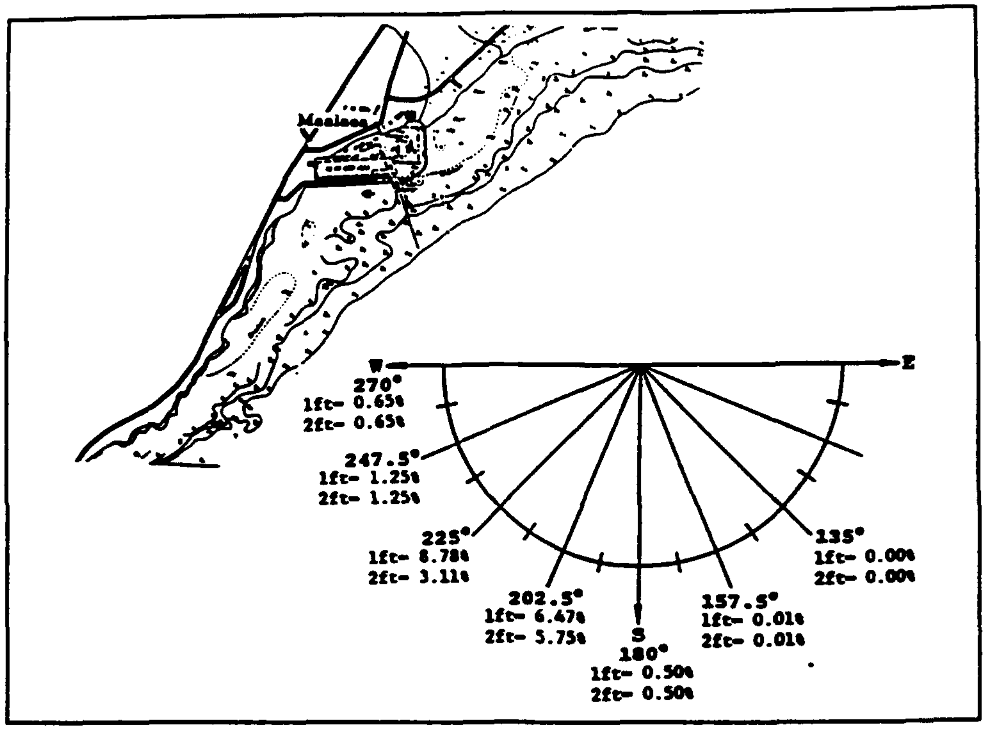

Figure 28. Plan 2 - Percent occurrence of wave heights exceeding 1- and 2-ft criteria

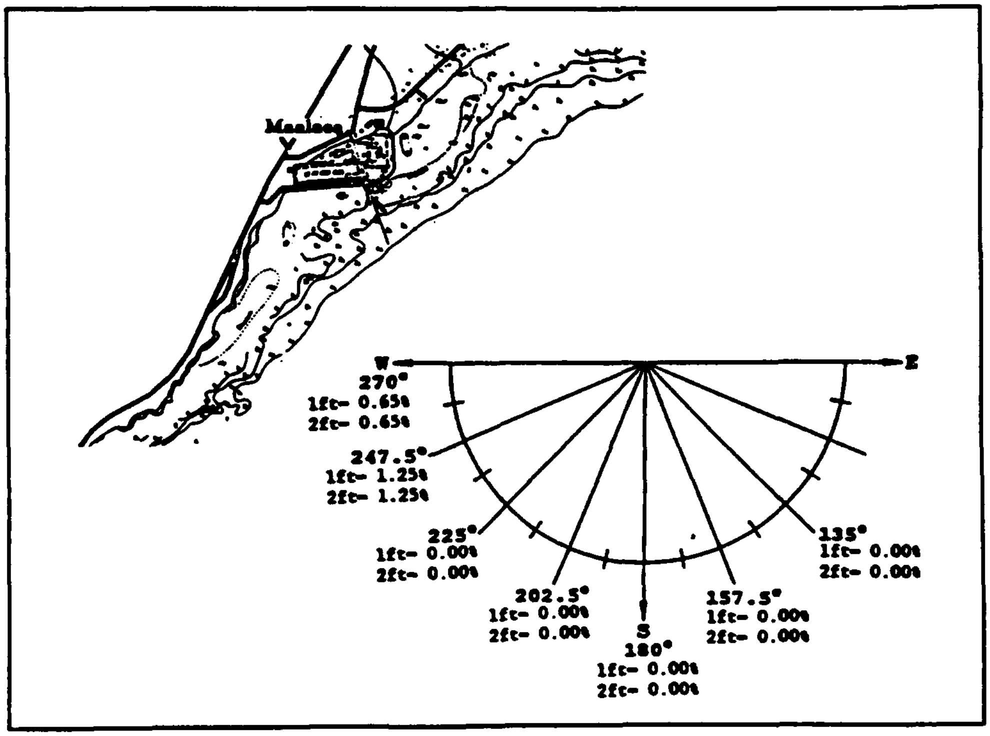

Figure 29. Plan 3 - Percent occurrence of wave heights exceeding 1- and 2-ft criteria

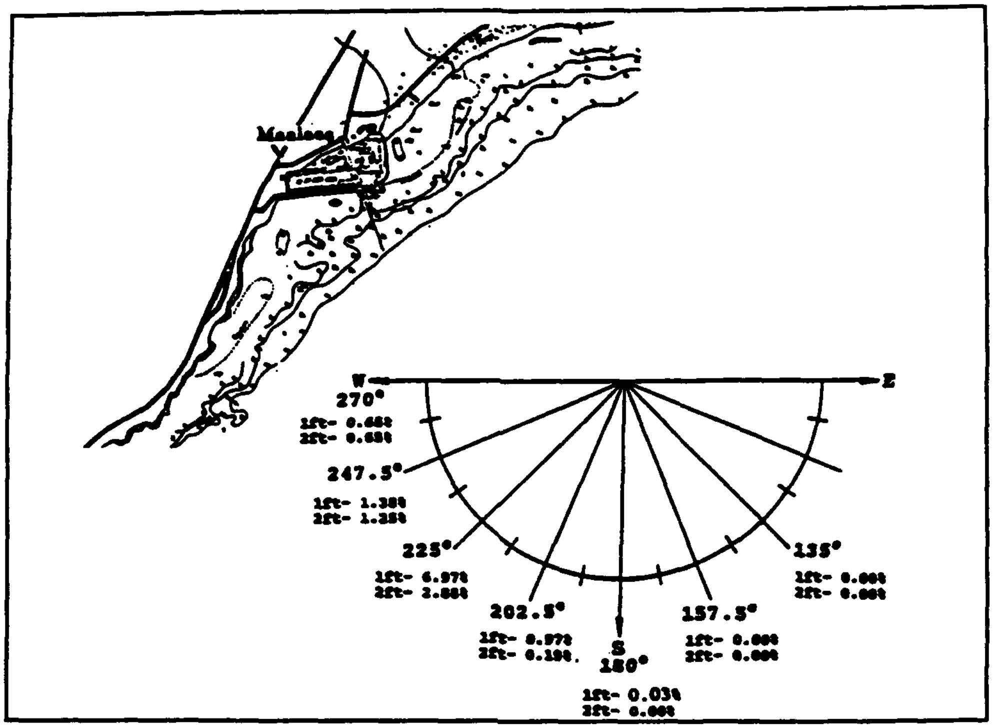

Figure 30. Plan 1a - Percent occurrence of wave heights exceeding 1- and 2-ft criteria

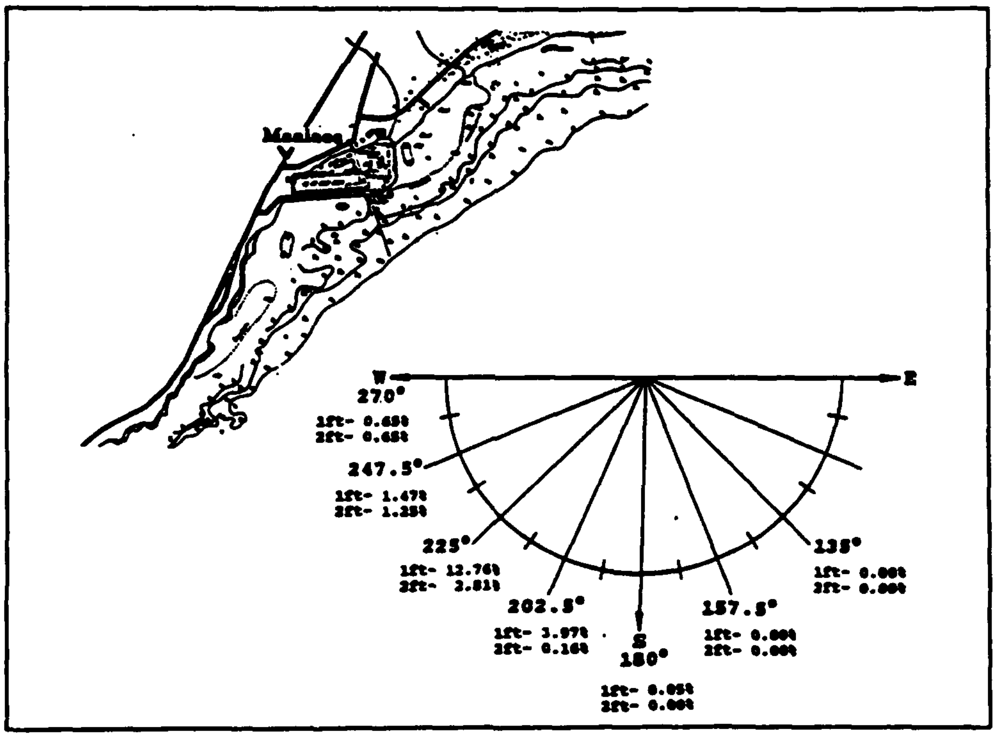

Figure 31. Plan 1b - Percent occurrence of wave heights exceeding 1- and 2-ft criteria

5 Conclusions

The numerical model studies and results described in this report should be seen in light of the following considerations:

a. The deepwater waves were based on measurements from MCCP data collected at Barbers Point, Oahu. Availability of incident wave data at the Maalaea Harbor vicinity would improve the validity of the overall results.

b. The revised SPM reflection coefficients were based on estimates from POD and were not reevaluated. Research in this area continues at CERC for better guidance.

c. The following assumptions were made in the implementation of the HARBD numerical model used in this study: (1) The model does not consider wave transmission through the breakwater, overtopping of structures, and wave breaking effects in the entrance channel. (2) Structure crest elevations were not tested or optimized. (3) Currents and nonlinear effects were neglected. (4) Diffraction around the structure ends was represented by diffraction around a blunt vertical wall with specified reflection coefficients. If wave transmission through the breakwater and overtopping of structures did occur in the harbor, the increased energy would result in larger wave heights than predicted. The presence of wave currents and breaking would increase hazardous navigation; however, wave breaking would reduce the energy in the harbor and result in lower wave heights than predicted. The primary effects which must be considered within a harbor such as Maalaea are wave refraction, diffraction, and dissipation effects, for which the model has been well verified.

d. The HARBD model uses monochromatic waves only.

e. The resulting percent occurrence of wave heights exceeding the 1- and 2-ft criteria is based on incident significant wave heights $H_{1/3}$. The use of H_{10} or H_1 would increase the incident wave heights by approximately 27 and 67 percent, respectively. Therefore, resulting wave heights inside the harbor would increase, and the percent occurrence of wave heights exceeding the 1- and 2-ft wave height criteria would increase.

Based on the results of this study, the following conclusions were reached:

a. The Existing Plan is unsatisfactory in providing the harbor with adequate protection against the incident wave climate.

b. The POD plan based on the GDM (Plan 1), which is directed toward the east, is satisfactory relative to the HQUSACE design criteria for protecting the harbor from the incident wave climate. Plan 1 is a recommended alternative.

c. Plan 2, which is directed toward the west, will not protect the harbor adequately from the deepwater waves from directions between south and west.

d. Plan 3, a modification to Plan 2, provides adequate protection from the incident wave climate since the additional east breakwater extension overlaps the existing south breakwater and permits very low energy inside the harbor. This plan is also a recommended alternative.

e. Plan 1a, similar to Plan 1, satisfies the HQUSACE design criteria. However, harbor performance relative to the criteria may be marginal in a few berthing locations, particularly along the existing wharf. Plan 1a is considered an acceptable alternative. It has an advantage relative to Plan 1 in that the south breakwater extension is farther west and may be less likely to affect the Maalaea Pipeline surfing area East of the harbor.

f. Plan 1b, with vertical sheet-pile bulkheads along the east face of the center mole, satisfies the criterion for entrance channel protection but fails to provide adequate protection of some of the more exposed harbor areas. Plan 1b is not recommended.

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Table 1
Percent Occurrence of Wave Heights Versus Direction

Wave Height ft	Wave Direction, deg (from which waves approach)							
	135.0	157.5	180.0	202.5	225.0	247.5	270.0	Total
0.00-1.00	0.00	0.00	0.01	0.02	0.02	0.02	0.00	0.07
1.01-2.00	*	0.03	0.91	3.97	4.32	1.33	0.28	10.84
2.01-3.00	*	0.07	0.86	5.34	11.05	4.16	2.04	23.52
3.01-4.00	0.00	0.01	0.28	4.26	11.60	3.81	2.24	22.20
4.01-5.00	0.00	0.00	0.04	2.28	8.63	2.28	1.88	15.11
5.01-6.00	0.00	0.00	0.02	1.13	5.14	1.52	0.77	8.58
6.01-7.00	0.00	0.00	*	1.81	3.38	0.96	1.22	7.37
7.01-8.00	0.00	0.00	0.09	0.96	3.64	0.83	0.82	6.34
8.01-9.00	0.00	0.00	0.00	0.19	3.00	0.21	0.66	4.06
9.01 +	0.00	0.00	0.00	0.00	0.00	1.25	0.65	1.90
TOTAL	0.01	0.11	2.21	19.96	50.78	16.37	10.56	100.0

Table 2
SHALWV Offshore and Transformed Wave Conditions

Deepwater			Transformed	
Period (sec)	**Height (ft)**	**Direction (deg)**	**Direction (deg)**	**Height (ft)**
9	3.00	135.0	160.0	0.91
1	3.00	135.0	162.0	0.81
3	3.00	135.0	166.0	0.75
15	3.00	135.0	170.0	0.73
17	3.00	135.0	173.0	0.69
20	3.00	135.0	175.0	0.69
9	3.00	157.5	168.0	1.62
11	3.00	157.5	170.0	1.48
13	3.00	157.5	171.0	1.73
15	3.00	157.5	173.0	1.26
17	3.00	157.5	174.0	1.16
20	3.00	157.5	175.0	1.07
9	3.00	180.0	176.0	1.72
11	3.00	180.0	176.0	1.62
13	3.00	180.0	177.0	1.57
15	3.00	180.0	177.0	1.45
17	3.00	180.0	177.0	1.38
20	3.00	180.0	177.0	1.23
9	3.00	202.5	180.0	1.19
11	3.00	202.5	179.0	1.13
13	3.00	202.5	178.0	1.10
15	3.00	202.5	178.0	1.00
17	3.00	202.5	178.0	0.94
20	3.00	202.5	177.0	0.84
9	3.00	225.0	193.0	0.88
11	3.00	225.0	191.0	0.84
13	3.00	225.0	189.0	0.78
15	3.00	225.0	188.0	0.75
17	3.00	225.0	186.0	0.69
20	3.00	225.0	184.0	0.69
9	3.00	247.5	199.0	0.53
11	3.00	247.5	194.0	0.53
13	3.00	247.5	191.0	0.56
15	3.00	247.5	189.0	0.56
17	3.00	247.5	187.0	0.59
20	3.00	247.5	186.0	0.62
9	3.00	270.0	198.0	0.40
11	3.00	270.0	193.0	0.40
13	3.00	270.0	191.0	0.43
15	3.00	270.0	189.0	0.46
17	3.00	270.0	187.0	0.49
20	3.00	270.0	186.0	0.49

(Sheet 1 of 5)

Table 2 (Continued)				
Deepwater			Transformed	
Period (sec)	Height (ft)	Direction (deg)	Direction (deg)	Height (ft)
9	4.00	135.0	160.0	1.16
11	4.00	135.0	162.0	1.03
13	4.00	135.0	166.0	0.94
15	4.00	135.0	170.0	0.91
17	4.00	135.0	173.0	0.88
20	4.00	135.0	175.0	0.84
9	4.00	157.5	168.0	2.03
11	4.00	157.5	170.0	1.74
13	4.00	157.5	171.0	1.68
15	4.00	157.5	173.0	1.58
17	4.00	157.5	174.0	1.52
20	4.00	157.5	175.0	1.36
9	4.00	180.0	176.0	2.22
11	4.00	180.0	176.0	2.13
13	4.00	180.0	177.0	2.04
15	4.00	180.0	177.0	1.91
17	4.00	180.0	177.0	1.75
20	4.00	180.0	177.0	1.61
9	4.00	202.5	183.0	1.69
11	4.00	202.5	182.0	1.64
13	4.00	202.5	181.0	1.48
15	4.00	202.5	181.0	1.48
17	4.00	202.5	181.0	1.41
20	4.00	202.5	180.0	1.26
9	4.00	225.0	198.0	1.45
11	4.00	225.0	195.0	1.35
13	4.00	225.0	193.0	1.29
15	4.00	225.0	192.0	1.19
17	4.00	225.0	190.0	1.13
20	4.00	225.0	188.0	1.05
9	4.00	247.5	203.0	0.78
11	4.00	247.5	198.0	0.81
13	4.00	247.5	195.0	0.88
15	4.00	247.5	192.0	0.91
17	4.00	247.5	191.0	0.94
20	4.00	247.5	190.0	1.00
9	4.00	270.0	202.0	0.59
11	4.00	270.0	197.0	0.62
13	4.00	270.0	194.0	0.69
15	4.00	270.0	192.0	0.72
17	4.00	270.0	191.0	0.78
20	4.00	270.0	189.0	0.81

(Sheet 2 of 5)

Table 2 (Continued)

Deepwater			Transformed	
Period (sec)	Height (ft)	Direction (deg)	Direction (deg)	Height (ft)
9	5.00	135.0	160.0	1.32
11	5.00	135.0	162.0	1.49
13	5.00	135.0	166.0	1.10
15	5.00	135.0	170.0	1.03
17	5.00	135.0	173.0	1.00
20	5.00	135.0	175.0	0.97
9	5.00	157.5	168.0	2.38
11	5.00	157.5	170.0	2.15
13	5.00	157.5	171.0	1.97
15	5.00	157.5	173.0	.86
17	5.00	157.5	174.0	1.73
20	5.00	157.5	175.0	1.57
9	5.00	180.0	176.0	2.62
11	5.00	180.0	176.0	2.51
13	5.00	180.0	177.0	2.37
15	5.00	180.0	177.0	2.13
17	5.00	180.0	177.0	2.18
20	5.00	180.0	177.0	1.84
9	5.00	202.5	183.0	2.04
11	5.00	202.5	182.0	1.86
13	5.00	202.5	181.0	1.80
15	5.00	202.5	181.0	1.67
17	5.00	202.5	181.0	1.57
20	5.00	202.5	180.0	1.37
9	5.00	225.0	198.0	1.64
11	5.00	225.0	195.0	1.54
13	5.00	225.0	193.0	1.44
15	5.00	225.0	192.0	1.38
17	5.00	225.0	190.0	1.29
20	5.00	225.0	188.0	1.19
9	5.00	247.5	203.0	0.91
11	5.00	247.5	198.0	0.94
13	5.00	247.5	195.0	1.00
15	5.00	247.5	192.0	1.03
17	5.00	247.5	191.0	1.08
20	5.00	247.5	190.0	1.13
9	5.00	270.0	202.0	0.65
11	5.00	270.0	197.0	0.73
13	5.00	270.0	194.0	0.73
15	5.00	270.0	192.0	0.84
17	5.00	270.0	191.0	0.88
20	5.00	270.0	189.0	0.94

(Sheet 3 of 5)

Table 2 (Continued)				
Offshore			**Transformed**	
Period (sec)	**Height (ft)**	**Direction (deg)**	**Direction (deg)**	**Height (ft)**
9	6.00	180.0	176.0	3.13
20	6.00	180.0	177.0	2.24
9	6.00	202.5	183.0	2.29
13	6.00	202.5	181.0	2.17
15	6.00	202.5	181.0	2.04
20	6.00	202.5	180.0	1.70
9	6.00	225.0	198.0	1.97
11	6.00	225.0	195.0	1.83
13	6.00	225.0	193.0	1.74
15	6.00	225.0	192.0	1.64
17	6.00	225.0	190.0	1.54
20	6.00	225.0	188.0	1.44
9	6.00	247.5	203.0	1.07
11	6.00	247.5	198.0	1.13
13	6.00	247.5	195.0	1.16
15	6.00	247.5	192.0	1.23
17	6.00	247.5	191.0	1.29
20	6.00	247.5	190.0	1.35
9	6.00	270.0	202.0	0.78
11	6.00	270.0	197.0	0.84
13	6.00	270.0	194.0	0.94
15	6.00	270.0	192.0	1.00
17	6.00	270.0	191.0	1.03
20	6.00	270.0	189.0	1.08
9	7.00	202.5	183.0	2.75
13	7.00	202.5	181.0	2.46
15	7.00	202.5	181.0	2.34
20	7.00	202.5	180.0	2.01
9	7.00	225.0	198.0	2.34
11	7.00	225.0	195.0	2.17
13	7.00	225.0	193.0	2.04
15	7.00	225.0	192.0	1.92
17	7.00	225.0	190.0	1.81
20	7.00	225.0	188.0	1.67
9	7.00	247.5	203.0	1.25
11	7.00	247.5	198.0	1.29
13	7.00	247.5	195.0	1.38
15	7.00	247.5	192.0	1.45
17	7.00	247.5	191.0	1.48
20	7.00	247.5	190.0	1.54
9	7.00	270.0	202.0	0.91
11	7.00	270.0	197.0	1.00

(Sheet 4 of 5)

Table 2 (Concluded)

Offshore			Transformed	
Period (sec)	**Height (ft)**	**Direction (deg)**	**Direction (deg)**	**Height (ft)**
13	7.00	270.0	194.0	1.10
15	7.00	270.0	192.0	1.16
17	7.00	270.0	191.0	1.19
20	7.00	270.0	189.0	1.29
13	8.00	225.0	194.0	1.80
15	8.00	225.0	192.0	2.20
17	8.00	225.0	190.0	2.05
20	8.00	225.0	188.0	1.89
9	8.00	247.5	202.0	1.64
11	8.00	247.5	198.0	1.45
13	8.00	247.5	195.0	1.57
15	8.00	247.5	192.0	1.64
17	8.00	247.5	191.0	1.70
20	8.00	247.5	190.0	1.77
9	8.00	270.0	202.0	1.03
11	8.00	270.0	197.0	1.13
13	8.00	270.0	194.0	1.23
15	8.00	270.0	192.0	1.32
17	8.00	270.0	191.0	1.38
20	8.00	270.0	189.0	1.45
15	9.00	225.0	192.0	2.43
17	9.00	225.0	190.0	2.31
20	9.00	225.0	188.0	2.14
9	9.00	247.5	202.0	1.64
11	9.00	247.5	198.0	1.64
13	9.00	247.5	195.0	1.73
15	9.00	247.5	192.0	1.84
17	9.00	247.5	191.0	1.89
20	9.00	247.5	190.0	1.99
9	9.00	270.0	202.0	1.23
11	9.00	270.0	197.0	1.26
13	9.00	270.0	194.0	1.38
15	9.00	270.0	192.0	1.44
17	9.00	270.0	191.0	1.54
20	9.00	270.0	189.0	1.63

(Sheet 5 of 5)

Table 3
HARBD Wave Amplification Factors
Existing Plan Wave Angle = 135.0 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	1.78	1.05	0.93	1.14	0.36	1.14
2	0.94	0.50	0.41	0.66	0.27	0.71
3	0.93	0.38	0.30	0.35	0.16	0.48
4	1.09	0.90	0.73	0.79	0.21	0.59
5	1.30	0.65	0.44	0.80	0.17	0.46
6	0.47	0.41	0.25	0.46	0.15	0.51
7	0.64	0.34	0.34	0.73	0.23	0.48
8	0.12	0.15	0.12	0.34	0.15	0.36
9	0.22	0.03	0.20	0.54	0.15	0.41
0	0.08	0.06	0.20	0.38	0.12	0.17
1	0.04	0.06	0.04	0.16	0.06	0.03
2	0.01	0.03	0.03	0.09	0.03	0.05
3	0.01	0.03	0.02	0.11	0.08	0.16
4	0.04	0.02	0.09	0.08	0.08	0.23
5	0.15	0.06	0.16	0.21	0.07	0.28
6	0.09	0.11	0.21	0.40	0.11	0.33

Table 4
HARBD Wave Amplification Factors
Existing Plan, Wave Angle = 157.5 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.65	1.08	0.67	1.20	0.65	0.61
2	0.18	0.78	0.37	0.74	0.42	0.41
3	0.14	0.44	0.30	0.39	0.22	0.26
4	1.20	0.77	0.59	0.81	0.40	0.24
5	0.56	0.83	0.36	0.76	0.45	0.24
6	0.10	0.39	0.24	0.53	0.25	0.25
7	0.12	0.57	0.28	0.77	0.44	0.32
8	0.10	0.18	0.12	0.35	0.24	0.23
9	0.21	0.39	0.17	0.60	0.31	0.24
0	0.14	0.17	0.11	0.42	0.25	0.14
1	0.07	0.06	0.01	0.16	0.12	0.06
2	0.02	0.02	0.01	0.09	0.06	0.04
3	0.04	0.06	0.03	0.07	0.14	0.11
4	0.13	0.12	0.06	0.07	0.12	0.15
5	0.08	0.23	0.07	0.27	0.13	0.07
6	0.09	0.11	0.05	0.47	0.18	0.16

Table 5
HARBD Wave Amplification Factors
Existing Plan, Wave Angle = 180.0 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.18	0.44	0.44	1.40	1.50	0.11
2	0.27	0.04	0.18	0.78	0.62	0.09
3	0.16	0.04	0.14	0.41	0.33	0.05
4	0.15	0.42	0.47	0.86	0.79	0.06
5	0.14	0.17	0.15	0.67	0.70	0.04
6	0.18	0.02	0.07	0.53	0.41	0.05
7	0.20	0.02	0.18	0.76	0.69	0.07
8	0.10	0.03	0.10	0.31	0.35	0.05
9	0.17	0.06	0.22	0.54	0.58	0.05
10	0.08	0.04	0.17	0.39	0.42	0.04
11	0.05	0.03	0.03	0.12	0.18	0.02
12	0.01	0.01	0.02	0.08	0.10	0.01
13	0.01	0.02	0.05	0.04	0.14	0.03
14	0.09	0.03	0.12	0.07	0.13	0.03
15	0.07	0.04	0.17	0.27	0.22	0.02
16	0.08	0.06	0.15	0.42	0.42	0.04

Table 6
HARBD Wave Amplification Factors
Existing Plan, Wave Angle = 202.5 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.45	1.24	0.81	0.62	1.45	0.10
2	0.07	0.43	0.52	0.24	0.61	0.08
3	0.04	0.50	0.44	0.17	0.32	0.05
4	0.12	0.75	0.70	0.47	0.78	0.05
5	0.12	0.64	0.26	0.31	0.68	0.04
6	0.02	0.32	0.25	0.19	0.40	0.04
7	0.08	0.38	0.44	0.16	0.68	0.07
8	0.08	0.20	0.24	0.06	0.34	0.05
9	0.28	0.27	0.56	0.05	0.58	0.05
10	0.20	0.18	0.38	0.02	0.42	0.04
11	0.11	0.13	0.12	0.02	0.18	0.02
12	0.02	0.03	0.03	0.01	0.10	0.01
13	0.07	0.08	0.13	0.03	0.14	0.02
14	0.16	0.16	0.28	0.01	0.13	0.03
15	0.14	0.16	0.33	0.03	0.22	0.02
16	0.25	0.17	0.26	0.06	0.42	0.03

Table 7
HARBD Wave Amplification Factors
Existing Plan, Wave Angle = 225.0 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	1.39	0.29	0.85	0.50	0.76	0.87
2	0.68	0.32	0.60	0.57	0.48	0.56
3	0.43	0.41	0.50	0.35	0.24	0.38
4	0.90	0.33	0.42	0.29	0.46	0.41
5	0.39	0.32	0.26	0.36	0.46	0.34
6	0.47	0.26	0.29	0.35	0.31	0.40
7	0.57	0.34	0.47	0.47	0.57	0.39
8	0.35	0.14	0.26	0.24	0.28	0.29
9	0.76	0.28	0.56	0.45	0.50	0.34
10	0.50	0.17	0.36	0.29	0.36	0.15
11	0.26	0.14	0.11	0.06	0.16	0.02
12	0.05	0.03	0.03	0.03	0.09	0.04
13	0.15	0.09	0.13	0.09	0.12	0.13
14	0.45	0.11	0.27	0.18	0.12	0.19
15	0.39	0.12	0.31	0.29	0.21	0.24
16	0.53	0.29	0.24	0.26	0.37	0.28

Table 8
HARBD Wave Amplification Factors
Existing Plan, Wave Angle = 247.5 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	1.26	0.72	0.63	0.77	0.51	0.80
2	0.87	0.46	0.66	0.46	0.40	0.53
3	0.60	0.41	0.41	0.24	0.24	0.35
4	0.89	0.56	0.20	0.46	0.19	0.37
5	0.53	0.37	0.37	0.48	0.26	0.31
6	0.64	0.27	0.38	0.30	0.22	0.38
7	0.70	0.32	0.56	0.51	0.35	0.36
8	0.39	0.17	0.27	0.26	0.23	0.27
9	0.69	0.24	0.52	0.45	0.24	0.32
0	0.43	0.09	0.35	0.32	0.18	0.14
11	0.22	0.06	0.06	0.14	0.09	0.02
12	0.05	0.02	0.04	0.08	0.05	0.04
13	0.12	0.04	0.10	0.11	0.12	0.12
14	0.40	0.07	0.20	0.10	0.13	0.18
15	0.35	0.10	0.33	0.18	0.10	0.22
16	0.40	0.12	0.30	0.33	0.16	0.26

Table 9
HARBD Wave Amplification Factors
Existing Plan, Wave Angle = 270.0 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	1.21	0.89	0.63	0.77	0.51	0.79
2	0.73	0.59	0.66	0.46	0.41	0.52
3	0.38	0.50	0.41	0.24	0.24	0.35
4	0.62	0.50	0.20	0.46	0.19	0.36
5	0.76	0.31	0.37	0.48	0.26	0.30
6	0.35	0.29	0.38	0.30	0.22	0.37
7	0.51	0.45	0.56	0.51	0.35	0.36
8	0.15	0.28	0.27	0.26	0.23	0.27
9	0.37	0.50	0.52	0.45	0.24	0.32
10	0.24	0.32	0.35	0.32	0.18	0.14
11	0.12	0.10	0.06	0.14	0.09	0.02
12	0.03	0.02	0.04	0.08	0.05	0.04
13	0.10	0.11	0.10	0.11	0.12	0.12
14	0.10	0.24	0.20	0.10	0.13	0.18
15	0.22	0.27	0.33	0.18	0.10	0.22
16	0.21	0.18	0.30	0.33	0.16	0.26

Table 10
HARBD Wave Amplification Factors
Plan 1, Wave Angle = 135.0 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.38	0.31	0.38	0.33	0.40	0.14
2	0.31	0.26	0.22	0.33	0.29	0.13
3	0.12	0.13	0.16	0.16	0.23	0.06
4	0.06	0.07	0.10	0.10	0.13	0.03
5	0.04	0.04	0.06	0.06	0.07	0.02
6	0.24	0.13	0.13	0.36	0.31	0.09
7	0.17	0.14	0.14	0.30	0.36	0.09
8	0.19	0.16	0.23	0.13	0.16	0.10
9	0.13	0.07	0.13	0.23	0.26	0.08
10	0.16	0.11	0.15	0.24	0.31	0.14
11	0.18	0.19	0.24	0.25	0.38	0.14
12	0.05	0.04	0.08	0.06	0.13	0.06
13	0.02	0.02	0.03	0.02	0.05	0.02
14	0.01	0.01	0.02	0.01	0.03	0.02
15	0.01	*	0.01	0.01	0.03	0.02
16	0.14	0.13	0.18	0.17	0.22	0.05
17	0.08	0.08	0.09	0.10	0.11	0.03
18	0.04	0.04	0.06	0.05	0.07	0.01
19	0.02	0.02	0.03	0.02	0.03	0.02
20	0.01	0.03	0.06	0.08	0.14	0.03
21	0.02	0.03	0.07	0.08	0.14	0.04
22	0.06	0.06	0.10	0.09	0.13	0.05
23	0.14	0.10	0.20	0.22	0.21	0.07

* Wave amplitude is below significance for tabulation.

Table 11
HARBD Wave Amplification Factors
Plan 1, Wave Angle = 157.5 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.14	0.57	0.61	0.21	0.43	0.32
2	0.15	0.31	0.43	0.19	0.40	0.20
3	0.03	0.20	0.28	0.10	0.25	0.17
4	0.02	0.10	0.17	0.06	0.15	0.09
5	0.01	0.07	0.11	0.04	0.08	0.05
6	0.11	0.11	0.38	0.17	0.51	0.13
7	0.11	0.11	0.14	0.16	0.47	0.21
8	0.11	0.11	0.41	0.10	0.12	0.15
9	0.09	0.09	0.23	0.13	0.31	0.18
10	0.10	0.10	0.18	0.13	0.33	0.25
11	0.10	0.10	0.42	0.13	0.42	0.27
12	0.03	0.03	0.14	0.03	0.13	0.10
13	0.01	0.01	0.05	0.01	0.05	0.04
14	*	*	0.03	*	0.03	0.03
15	0.01	0.01	0.02	*	0.03	0.03
16	0.04	0.04	0.31	0.10	0.26	0.15
17	0.02	0.02	0.15	0.06	0.14	0.08
18	0.01	0.01	0.10	0.03	0.08	0.05
19	0.01	0.01	0.06	0.01	0.03	0.03
20	0.01	0.01	0.10	0.05	0.14	0.11
21	*	*	0.11	0.05	0.13	0.11
22	0.01	0.16	0.17	0.07	0.10	0.11
23	0.03	0.23	0.31	0.14	0.25	0.18

* Wave amplitude is below significance for tabulation.

Table 12
HARBD Wave Amplification Factors
Plan 1, Wave Angle = 180.0 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.23	0.56	0.63	0.22	0.24	0.37
2	0.07	0.29	0.45	0.13	0.23	0.27
3	0.13	0.22	0.29	0.12	0.12	0.22
4	0.07	0.12	0.18	0.07	0.07	0.12
5	0.04	0.09	0.12	0.04	0.04	0.07
6	0.10	0.09	0.41	0.04	0.27	0.29
7	0.10	0.21	0.36	0.04	0.23	0.33
8	0.05	0.17	0.42	0.07	0.10	0.14
9	0.06	0.06	0.24	0.04	0.17	0.24
10	0.07	0.09	0.18	0.07	0.17	0.28
11	0.05	0.29	0.43	0.11	0.18	0.35
12	0.01	0.06	0.14	0.03	0.04	0.12
13	0.01	0.02	0.05	0.01	0.02	0.05
14	*	0.01	0.03	*	0.01	0.03
15	*	0.01	0.02	*	0.01	0.03
16	0.13	0.26	0.32	0.12	0.12	0.20
17	0.07	0.13	0.16	0.06	0.07	0.10
18	0.03	0.05	0.10	0.03	0.03	0.06
19	0.02	0.05	0.06	0.02	0.01	0.03
20	0.02	0.06	0.10	0.05	0.06	0.13
21	0.03	0.05	0.12	0.05	0.06	0.13
22	0.06	0.13	0.18	0.08	0.07	0.12
23	0.14	0.26	0.33	0.15	0.16	0.20

* Wave amplitude is below significance for tabulation.

Table 13
HARBD Wave Amplification Factors
Plan 1, Wave Angle = 202.5 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.51	0.44	0.50	0.69	0.16	0.37
2	0.29	0.24	0.44	0.40	0.13	0.27
3	0.25	0.18	0.24	0.30	0.09	0.22
4	0.13	0.11	0.15	0.18	0.05	0.12
5	0.08	0.08	0.10	0.11	0.03	0.07
6	0.09	0.08	0.41	0.25	0.15	0.29
7	0.06	0.13	0.35	0.28	0.13	0.33
8	0.15	0.17	0.34	0.39	0.05	0.14
9	0.04	0.06	0.20	0.23	0.09	0.24
10	0.02	0.09	0.08	0.24	0.08	0.28
11	0.18	0.29	0.36	0.39	0.10	0.35
12	0.05	0.06	0.11	0.13	0.02	0.12
13	0.02	0.02	0.03	0.05	0.01	0.05
14	0.01	0.01	0.02	0.03	*	0.03
15	*	0.01	0.01	0.02	*	0.03
16	0.26	0.26	0.26	0.32	0.09	0.20
17	0.15	0.13	0.13	0.17	0.05	0.10
18	0.07	0.05	0.08	0.10	0.02	0.06
19	0.04	0.05	0.05	0.06	0.01	0.03
20	0.04	0.06	0.08	0.11	0.04	0.13
21	*0.05*	*0.05*	*0.10*	*0.12*	*0.04*	*0.13*
22	0.11	0.13	0.14	0.17	0.05	0.12
23	0.24	0.26	0.23	0.35	0.12	0.20

Table 14
HARBD Wave Amplification Factors
Plan 1, Wave Angle = 225.0 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.68	0.68	0.56	0.77	0.36	0.27
2	0.54	0.46	0.52	0.48	0.32	0.25
3	0.31	0.35	0.27	0.33	0.19	0.15
4	0.17	0.15	0.17	0.20	0.12	0.09
5	0.10	0.10	0.11	0.12	0.07	0.05
6	0.22	0.18	0.53	0.34	0.32	0.10
7	0.30	0.36	0.43	0.36	0.26	0.11
8	0.38	0.30	0.42	0.47	0.12	0.18
9	0.12	0.14	0.25	0.30	0.20	0.11
10	0.17	0.10	0.10	0.29	0.21	0.22
11	0.42	0.36	0.44	0.45	0.26	0.24
12	0.09	0.09	0.13	0.15	0.06	0.11
13	0.05	0.02	0.04	0.06	0.02	0.05
14	0.02	0.01	0.03	0.04	0.01	0.03
15	0.01	0.01	0.02	0.02	0.01	0.04
16	0.32	0.28	0.29	0.35	0.19	0.14
17	0.18	0.13	0.14	0.19	0.11	0.07
18	0.08	0.06	0.09	0.11	0.05	0.03
19	0.05	0.06	0.06	0.06	0.02	0.05
20	0.06	0.07	0.09	0.12	0.10	0.09
21	0.05	0.06	0.11	0.14	0.09	0.12
22	0.13	0.12	0.15	0.19	0.11	0.12
23	0.27	0.25	0.25	0.38	0.26	0.20

Table 15
HARBD Wave Amplification Factors
Plan 1, Wave Angle = 247.5 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.78	0.48	0.74	0.35	0.47	0.26
2	0.65	0.44	0.46	0.32	0.34	0.25
3	0.32	0.23	0.32	0.19	0.27	0.15
4	0.18	0.15	0.19	0.11	0.15	0.09
5	0.11	0.09	0.12	0.07	0.08	0.05
6	0.27	0.43	0.33	0.33	0.40	0.10
7	0.42	0.36	0.35	0.27	0.46	0.10
8	0.50	0.35	0.45	0.12	0.18	0.17
9	0.19	0.21	0.29	0.20	0.32	0.10
10	0.25	0.09	0.28	0.21	0.36	0.22
11	0.54	0.37	0.44	0.25	0.45	0.24
12	0.11	0.11	0.14	0.06	0.16	0.11
13	0.06	0.04	0.06	0.02	0.06	0.04
14	0.02	0.02	0.03	0.01	0.04	0.03
15	0.01	0.01	0.02	0.01	0.04	0.04
16	0.34	0.25	0.34	0.19	0.25	0.14
17	0.19	0.13	0.18	0.11	0.12	0.07
18	0.08	0.07	0.11	0.05	0.08	0.03
19	0.06	0.05	0.06	0.02	0.04	0.05
20	0.06	0.08	0.12	0.09	0.16	0.09
21	0.05	0.09	0.13	0.09	0.16	0.11
22	0.12	0.13	0.18	0.11	0.15	0.12
23	0.28	0.21	0.36	0.25	0.23	0.20

Table 16
HARBD Wave Amplification Factors
Plan 1, Wave Angle = 270.0 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.62	0.47	0.75	0.35	0.47	0.26
2	0.40	0.44	0.46	0.32	0.34	0.25
3	0.21	0.23	0.32	0.19	0.27	0.15
4	0.11	0.15	0.19	0.11	0.15	0.09
5	0.08	0.09	0.12	0.07	0.08	0.05
6	0.47	0.44	0.33	0.33	0.40	0.10
7	0.28	0.36	0.35	0.27	0.46	0.10
8	0.27	0.35	0.45	0.12	0.18	0.17
9	0.11	0.21	0.29	0.20	0.32	0.10
10	0.27	0.09	0.28	0.21	0.36	0.22
11	0.54	0.37	0.44	0.25	0.45	0.24
12	0.10	0.11	0.14	0.06	0.16	0.11
13	0.03	0.04	0.06	0.02	0.06	0.04
14	0.02	0.02	0.03	0.01	0.04	0.03
15	0.01	0.01	0.02	0.01	0.04	0.04
16	0.28	0.25	0.34	0.19	0.25	0.14
17	0.13	0.13	0.18	0.11	0.12	0.07
18	0.06	0.07	0.11	0.05	0.08	0.03
19	0.05	0.05	0.06	0.02	0.04	0.05
20	0.06	0.08	0.12	0.09	0.16	0.09
21	0.04	0.09	0.13	0.09	0.16	0.11
22	0.18	0.13	0.18	0.11	0.15	0.12
23	0.28	0.21	0.36	0.25	0.23	0.20

Table 17
HARBD Wave Amplification Factors
Plan 2, Wave Angle = 135.0 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	1.07	1.35	1.32	0.94	0.94	0.46
2	0.77	0.89	0.71	0.59	0.61	0.32
3	0.47	0.64	0.83	0.31	0.76	0.23
4	0.15	0.33	0.84	0.30	0.41	0.15
5	0.09	0.21	0.23	0.13	0.15	0.08
6	0.03	0.07	0.09	0.06	0.19	0.06
7	0.65	0.68	0.69	0.50	0.38	0.24
8	0.39	0.59	0.56	0.25	0.56	0.18
9	0.21	0.31	0.32	0.30	0.40	0.17
10	0.29	0.29	0.39	0.17	0.31	0.09
11	0.21	0.28	0.28	0.18	0.25	0.11
12	0.12	0.20	0.32	0.05	0.35	0.12
13	0.02	0.05	0.01	0.04	0.14	0.07
14	0.02	0.01	0.01	0.02	0.05	0.03
15	*	0.01	0.01	0.01	0.04	0.03
16	0.01	0.01	0.01	0.01	0.03	0.02
17	0.13	0.31	0.68	0.02	0.38	0.18
18	0.09	0.21	0.45	0.15	0.22	0.14
19	0.03	0.12	0.20	0.09	0.15	0.10
20	0.02	0.08	0.19	0.06	0.16	0.12
21	0.02	0.09	0.11	0.09	0.10	0.06
22	0.06	0.10	0.26	0.05	0.22	0.17
23	0.18	0.34	0.81	0.33	0.31	0.32

* Wave amplitude is below significance for tabulation.

Table 18
HARBD Wave Amplification Factors
Plan 2, Wave Angle = 157.5 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	1.59	1.20	0.46	0.83	0.78	1.00
2	1.06	0.85	0.32	0.49	0.54	0.67
3	0.79	0.85	0.23	0.33	0.57	0.70
4	0.71	0.65	0.15	0.25	0.33	0.43
5	0.28	0.19	0.08	0.07	0.09	0.22
6	0.14	0.08	0.06	0.08	0.15	0.20
7	0.47	0.74	0.24	0.27	0.22	0.52
8	0.50	0.53	0.18	0.33	0.40	0.55
9	0.54	0.35	0.17	0.14	0.25	0.43
10	0.33	0.34	0.09	0.18	0.21	0.29
11	0.40	0.26	0.11	0.11	0.15	0.27
12	0.18	0.25	0.63	0.17	0.22	0.35
13	0.09	0.02	0.07	0.03	0.07	0.17
14	0.03	0.02	0.03	0.01	0.03	0.06
15	0.01	0.01	0.03	0.01	0.02	0.06
16	0.01	0.01	0.02	*	0.01	0.04
17	0.57	0.51	0.18	0.19	0.29	0.40
18	0.27	0.39	0.14	0.11	0.17	0.24
19	0.13	0.19	0.10	0.06	0.10	0.19
20	0.13	0.14	0.12	0.08	0.12	0.23
21	0.22	0.12	0.06	0.04	0.07	0.15
22	0.17	0.22	0.17	0.16	0.20	0.31
23	0.64	0.70	0.32	0.13	0.27	0.47

* Wave amplitude is below significance for tabulation.

Table 19
HARBD Wave Amplification Factors
Plan 2, Wave Angle = 180.0 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	1.56	1.45	1.16	0.21	0.94	0.91
2	1.27	1.04	0.60	0.16	0.62	0.67
3	0.62	0.85	0.39	0.07	0.75	0.35
4	0.49	0.56	0.38	0.08	0.41	0.15
5	0.16	0.16	0.10	0.02	0.15	0.12
6	0.07	0.06	0.09	0.03	0.19	0.04
7	0.68	0.91	0.51	0.08	0.38	0.61
8	0.45	0.56	0.45	0.07	0.31	0.56
9	0.55	0.35	0.18	0.02	0.40	0.14
10	0.30	0.35	0.26	0.02	0.30	0.19
11	0.35	0.25	0.17	0.01	0.25	0.14
12	0.07	0.26	0.24	0.02	0.35	0.08
13	0.08	0.02	0.03	*	0.14	0.02
14	0.03	0.02	0.01	*	0.05	0.01
15	0.01	0.01	*	*	0.04	*
16	0.02	0.01	*	*	0.03	*
17	0.34	0.44	0.29	0.07	0.38	0.15
18	0.22	0.32	0.17	0.04	0.21	0.11
19	0.09	0.16	0.08	0.02	0.15	0.04
20	0.07	0.12	0.11	0.03	0.16	0.03
21	0.14	0.10	0.04	0.01	0.10	0.03
22	0.11	0.18	0.18	0.05	0.22	0.08
23	0.49	0.59	0.19	0.05	0.30	0.23

* Wave amplitude is below significance for tabulation.

Table 20
HARBD Wave Amplification Factors
Plan 2, Wave Angle = 202.5 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.76	0.66	1.55	0.20	0.77	1.51
2	0.46	0.55	0.86	0.17	0.53	1.05
3	0.18	0.46	0.69	0.10	0.61	0.41
4	0.38	0.26	0.62	0.11	0.31	0.24
5	0.18	0.09	0.15	0.02	0.11	0.21
6	0.08	0.04	0.06	0.04	0.14	0.08
7	0.26	0.54	0.80	0.08	0.32	0.80
8	0.11	0.31	0.56	0.08	0.47	0.50
9	0.22	0.24	0.28	0.03	0.33	0.20
10	0.11	0.18	0.36	0.03	0.25	0.25
11	0.14	0.15	0.25	0.02	0.21	0.22
12	0.04	0.11	0.30	0.03	0.28	0.14
13	0.03	0.02	0.02	0.01	0.11	0.03
14	0.01	0.01	0.01	*	0.04	0.01
15	*	*	*	*	0.03	*
16	*	*	*	*	0.03	*
17	0.27	0.19	0.49	0.08	0.29	0.24
18	0.20	0.15	0.32	0.05	0.16	0.18
19	0.12	0.08	0.13	0.02	0.11	0.13
20	0.08	0.05	0.13	0.03	0.12	0.08
21	0.12	0.06	0.07	0.01	0.07	0.10
22	0.08	0.09	0.17	0.06	0.16	0.12
23	0.51	0.26	0.56	0.07	0.22	0.34

* Wave amplitude is below significance for tabulation.

Table 21
HARBD Wave Amplification Factors
Plan 2, Wave Angle = 225.0 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.87	0.94	0.35	0.77	0.20	0.48
2	0.71	0.58	0.19	0.60	0.13	0.42
3	0.38	0.45	0.06	0.53	0.15	0.22
4	0.13	0.29	0.13	0.39	0.13	0.42
5	0.07	0.11	0.03	0.10	0.07	0.33
6	0.03	0.05	0.01	0.15	0.05	0.12
7	0.56	0.50	0.18	0.23	0.11	0.37
8	0.43	0.31	0.08	0.40	0.09	0.18
9	0.17	0.25	0.04	0.20	0.10	0.16
10	0.21	0.19	0.06	0.21	0.04	0.15
11	0.18	0.15	0.04	0.14	0.06	0.18
12	0.13	0.11	0.06	0.21	0.07	0.10
13	0.02	0.02	0.01	0.04	0.04	0.02
14	0.01	0.01	*	0.02	0.02	*
15	*	0.01	*	0.01	0.02	*
16	*	0.01	*	0.01	0.01	*
17	0.11	0.21	0.10	0.31	0.15	0.41
18	0.08	0.18	0.07	0.18	0.11	0.29
19	0.04	0.10	0.03	0.09	0.08	0.19
20	0.03	0.06	0.03	0.13	0.09	0.12
21	0.03	0.07	0.01	0.07	0.04	0.16
22	0.03	0.11	0.04	0.25	0.13	0.20
23	0.11	0.30	0.11	0.25	0.26	0.59

* Wave amplitude is below significance for tabulation.

Table 22
HARBD Wave Amplification Factors
Plan 2, Wave Angle = 247.5 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.74	0.94	0.13	0.92	0.55	0.30
2	0.61	0.54	0.03	0.69	0.38	0.21
3	0.36	0.34	0.11	0.60	0.43	0.18
4	0.12	0.18	0.15	0.42	0.22	0.15
5	0.07	0.05	0.04	0.10	0.08	0.08
6	0.02	0.02	0.12	0.16	0.10	0.05
7	0.44	0.53	0.01	0.27	0.22	0.16
8	0.38	0.25	0.05	0.46	0.33	0.13
9	0.17	0.17	0.05	0.24	0.24	0.12
10	0.20	0.13	0.06	0.25	0.19	0.06
11	0.18	0.10	0.04	0.16	0.15	0.07
12	0.12	0.07	0.05	0.25	0.21	0.08
13	0.02	0.02	*	0.05	0.08	0.05
14	0.01	0.01	*	0.02	0.03	0.02
15	*	*	*	0.01	0.03	0.02
16	*	0.01	*	0.01	0.02	0.02
17	0.10	0.12	0.12	0.33	0.20	0.18
18	0.07	0.09	0.08	0.19	0.11	0.13
19	0.03	0.04	0.04	0.10	0.08	0.09
20	0.02	0.03	0.03	0.14	0.08	0.11
21	0.03	0.03	0.21	0.08	0.05	0.05
22	0.04	0.05	0.05	0.27	0.11	0.15
23	0.12	0.14	0.14	0.27	0.15	0.30

* Wave amplitude is below significance for tabulation.

Table 23
HARBD Wave Amplification Factors
Plan 2, Wave Angle = 270.0 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.67	0.77	0.13	0.92	0.55	0.32
2	0.36	0.49	0.05	0.69	0.38	0.23
3	0.28	0.44	0.11	0.60	0.43	0.19
4	0.31	0.32	0.15	0.42	0.22	0.16
5	0.13	0.12	0.04	0.10	0.08	0.08
6	0.06	0.06	0.02	0.16	0.10	0.06
7	0.19	0.45	0.01	0.27	0.22	0.18
8	0.17	0.27	0.05	0.46	0.33	0.14
9	0.18	0.25	0.05	0.24	0.24	0.13
10	0.11	0.19	0.06	0.25	0.19	0.06
11	0.13	0.16	0.04	0.16	0.15	0.08
12	0.07	0.12	0.05	0.25	0.21	0.09
13	0.03	0.02	*	0.05	0.08	0.05
14	0.01	0.01	*	0.02	0.03	0.02
15	*	0.01	*	0.01	0.03	0.02
16	*	0.01	*	0.01	0.02	0.02
17	0.25	0.24	0.12	0.33	0.20	0.18
18	0.13	0.20	0.08	0.19	0.11	0.14
19	0.06	0.11	0.04	0.10	0.08	0.10
20	0.06	0.07	0.03	0.14	0.08	0.11
21	0.10	0.08	0.02	0.08	0.05	0.05
22	0.06	0.13	0.05	0.27	0.11	0.16
23	0.29	0.36	0.14	0.27	0.15	0.31

* Wave amplitude is below significance for tabulation.

Table 24
HARBD Wave Amplification Factors
Plan 3, Wave Angle = 135.0 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.58	0.67	0.49	0.42	0.25	0.14
2	0.34	0.31	0.31	0.27	0.14	0.09
3	0.16	0.17	0.14	0.16	0.09	0.05
4	0.12	0.17	0.12	0.14	0.08	0.03
5	0.11	0.09	0.12	0.12	0.06	0.03
6	0.05	0.05	0.03	0.02	0.01	0.01
7	0.03	0.03	0.01	0.02	0.01	0.01
8	0.08	0.10	0.08	0.08	0.07	0.04
9	0.10	0.11	0.09	0.09	0.06	0.02
10	0.05	0.08	0.04	0.05	0.04	0.02
11	0.08	0.06	0.06	0.05	0.03	0.01
12	0.06	0.08	0.04	0.03	0.02	0.01
13	0.03	0.07	0.04	0.05	0.03	0.01
14	0.01	0.02	*	0.01	0.01	0.01
15	*	*	*	*	*	*
16	*	*	0.21	*	0.11	*
17	*	*	*	*	*	*
18	0.08	0.07	0.07	0.06	0.04	0.02
19	0.05	0.04	0.04	0.03	0.02	0.01
20	0.03	0.02	0.02	0.01	0.01	0.01
21	0.02	0.01	0.01	0.01	0.01	0.01
22	0.02	0.02	0.01	0.01	0.01	0.01
23	0.05	0.02	0.04	0.05	0.03	0.01
24	0.15	0.11	0.11	0.08	0.05	0.04

* Wave amplitude is below significance for tabulation.

Table 25
HARBD Wave Amplification Factors
Plan 3, Wave Angle = 157.5 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.42	0.25	0.37	0.37	0.35	0.07
2	0.23	0.08	0.25	0.24	0.21	0.05
3	0.15	0.56	0.13	0.14	0.13	0.03
4	0.12	0.05	0.11	0.12	0.12	0.03
5	0.08	0.04	0.08	0.11	0.10	0.02
6	0.04	0.02	0.03	0.02	0.02	0.01
7	0.02	0.01	*	0.02	0.02	0.01
8	0.08	0.03	0.07	0.06	0.08	0.03
9	0.09	0.02	0.06	0.08	0.08	0.02
10	0.05	0.04	0.05	0.04	0.05	0.01
11	0.07	0.02	0.04	0.05	0.04	0.01
12	0.06	0.03	0.03	0.03	0.03	0.01
13	0.03	0.02	0.03	0.05	0.05	0.01
14	0.01	0.01	*	0.01	0.01	0.01
15	*	*	*	*	*	*
16	*	*	*	*	*	*
17	*	*	*	*	*	*
18	0.06	0.02	0.05	0.06	0.05	0.01
19	0.04	0.01	0.03	0.03	0.03	0.01
20	0.02	0.01	0.01	0.01	0.01	*
21	0.01	0.01	0.01	0.01	0.01	*
22	0.01	0.01	0.01	0.01	0.01	*
23	0.04	0.01	0.02	0.04	0.04	0.01
24	0.11	0.04	0.08	0.07	0.07	0.02

* Wave amplitude is below significance for tabulation.

Table 26
HARBD Wave Amplification Factors
Plan 3, Wave Angle = 180.0 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.51	0.26	0.13	0.28	0.35	0.16
2	0.35	0.17	0.10	0.19	0.22	0.09
3	0.18	0.12	0.05	0.11	0.14	0.06
4	0.15	0.08	0.04	0.10	0.12	0.06
5	0.09	0.07	0.02	0.09	0.10	0.04
6	0.05	0.04	0.01	0.02	0.02	0.01
7	0.03	0.02	*	0.01	0.02	0.01
8	0.10	0.08	0.03	0.05	0.07	0.05
9	0.11	0.05	0.03	0.07	0.08	0.04
10	0.07	0.06	0.01	0.03	0.04	0.03
11	0.06	0.04	0.01	0.04	0.04	0.02
12	0.08	0.04	0.01	0.03	0.03	0.02
13	0.06	0.02	0.01	0.04	0.04	0.02
14	0.01	0.01	*	*	0.01	0.01
15	*	*	*	*	*	*
16	*	*	*	*	*	*
17	*	*	*	*	*	*
18	0.07	0.04	0.01	0.05	0.05	0.03
19	0.04	0.02	0.01	0.03	0.03	0.02
20	0.02	0.01	*	0.01	0.01	0.01
21	0.01	0.01	*	0.01	0.01	0.01
22	0.03	0.02	*	0.05	0.01	0.01
23	0.04	0.02	*	0.05	0.04	0.02
24	0.12	0.08	0.02	*	0.07	0.03

* Wave amplitude is below significance for tabulation.

Table 27
HARBD Wave Amplification Factors
Plan 3, Wave Angle = 202.5 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.18	0.21	0.05	0.23	0.32	0.06
2	0.13	0.19	0.04	0.16	0.20	0.04
3	0.05	0.10	0.03	0.10	0.13	0.03
4	0.05	0.08	0.01	0.09	0.11	0.03
5	0.02	0.06	*	0.08	0.09	0.02
6	0.01	0.03	*	0.03	0.02	*
7	0.01	0.01	*	*	0.02	*
8	0.03	0.09	0.02	0.06	0.06	0.02
9	0.03	0.05	0.01	0.07	0.07	0.02
10	0.02	0.06	0.01	0.0[illegible]	0.04	0.01
11	0.02	0.03	0.01	0.04	0.04	0.01
12	0.02	0.03	*	0.03	0.03	0.01
13	0.02	0.01	*	0.03	0.04	0.01
14	*	0.01	*	*	0.01	*
15	*	*	*	*	*	*
16	*	*	*	*	*	*
17	*	*	0.49	*	*	*
18	0.02	0.04	*	0.05	0.05	0.01
19	0.01	0.03	*	0.03	0.03	*
20	*	0.01	*	0.01	0.01	*
21	*	0.01	*	0.01	0.01	*
22	0.01	0.02	*	0.01	0.01	*
23	0.01	0.01	*	0.03	0.04	0.01
24	0.03	0.07	0.01	0.08	0.06	0.01

* Wave amplitude is below significance for tabulation.

Table 28
HARBD Wave Amplification Factors
Plan 3, Wave Angle = 225.0

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.14	0.32	0.28	0.16	0.14	0.25
2	0.14	0.25	0.16	0.11	0.09	0.17
3	0.07	0.11	0.07	0.09	0.06	0.11
4	0.07	0.09	0.09	0.07	0.05	0.07
5	0.04	0.07	0.08	0.07	0.04	0.05
6	0.02	0.03	0.03	0.02	0.01	0.02
7	0.01	0.01	*	*	0.01	0.01
8	0.04	0.09	0.06	0.05	0.03	0.08
9	0.04	0.06	0.06	0.06	0.03	0.05
10	0.03	0.07	0.04	0.03	0.02	0.04
11	0.03	0.04	0.03	0.03	0.02	0.03
12	0.03	0.04	0.03	0.02	0.02	0.03
13	0.03	0.01	0.01	0.02	0.02	0.03
14	0.01	0.01	0.01	*	*	0.02
15	*	*	*	*	*	0.01
16	*	*	*	*	*	0.01
17	*	*	*	*	*	*
18	0.03	0.04	0.04	0.04	0.02	0.04
19	0.02	0.03	0.03	0.02	0.01	0.03
20	0.01	0.01	0.01	0.01	0.01	0.02
21	0.01	0.01	0.01	0.01	0.01	0.01
22	0.01	0.02	0.02	0.01	0.01	0.01
23	0.01	0.02	0.02	0.02	0.02	0.03
24	0.05	0.08	0.09	0.07	0.03	0.08

* Wave amplitude is below significance for tabulation.

Table 29
HARBD Wave Amplification Factors
Plan 3, Wave Angle = 247.4 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.22	0.29	0.09	0.05	0.24	0.24
2	0.16	0.17	0.05	0.05	0.11	0.17
3	0.16	0.07	0.06	0.03	0.06	0.11
4	0.07	0.09	0.05	0.02	0.06	0.07
5	0.03	0.08	0.04	0.02	0.05	0.05
6	0.02	0.03	0.01	*	0.01	0.02
7	0.01	0.01	*	*	0.01	0.01
8	0.04	0.06	0.03	0.01	0.05	0.08
9	0.05	0.06	0.04	0.02	0.04	0.05
10	0.03	0.04	0.02	*	0.03	0.04
11	0.03	0.03	0.02	0.01	0.02	0.03
12	0.04	0.03	0.01	0.01	0.02	0.03
13	0.03	0.01	0.01	0.09	0.02	0.03
14	0.01	0.01	*	*	0.01	0.02
15	*	*	*	*	*	0.01
16	*	*	*	*	*	0.01
17	*	*	*	*	*	*
18	0.03	0.04	0.03	0.01	0.03	0.04
19	0.01	0.03	0.02	0.01	0.02	0.03
20	0.01	0.01	0.01	*	0.01	0.02
21	0.01	0.01	*	*	0.01	0.01
22	0.01	0.02	0.01	*	0.01	0.01
23	0.01	0.02	0.01	0.01	0.02	0.03
24	0.05	0.08	0.04	0.01	0.04	0.08

* Wave amplitude is below significance for tabulation.

Table 30
HARBD Wave Amplification Factors
Plan 3, Wave Angle = 270.0 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.27	0.30	0.09	0.05	0.24	0.24
2	0.27	0.18	0.05	0.05	0.11	0.17
3	0.16	0.07	0.06	0.03	0.06	0.11
4	0.10	0.10	0.05	0.02	0.06	0.07
5	0.06	0.08	0.04	0.02	0.05	0.05
6	0.04	0.03	0.02	*	0.01	0.02
7	0.02	0.01	*	*	0.01	0.01
8	0.09	0.07	0.04	0.01	0.05	0.08
9	0.06	0.06	0.04	0.02	0.04	0.05
10	0.07	0.05	0.02	0.01	0.03	0.04
11	0.04	0.03	0.02	0.01	0.02	0.03
12	0.05	0.03	0.01	0.01	0.02	0.03
13	0.03	0.02	0.02	0.01	0.02	0.03
14	0.02	0.01	*	*	0.01	0.02
15	*	*	*	*	*	0.01
16	*	*	*	*	*	0.01
17	*	*	*	*	*	*
18	0.04	0.05	0.03	0.01	0.03	0.04
19	0.03	0.03	0.02	0.01	0.02	0.03
20	0.01	0.01	0.01	*	0.01	0.02
21	0.01	0.01	*	*	0.01	0.01
22	0.02	0.02	0.01	*	0.01	0.01
23	0.02	0.03	0.02	0.01	0.02	0.03
24	0.08	0.09	0.05	0.01	0.04	0.08

* Wave amplitude is below significance for tabulation.

Table 31
HARBD Wave Amplification Factors
Plan 1a, Wave Angle = 135.0 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.52	0.41	0.44	0.10	0.29	0.20
2	0.41	0.28	0.27	0.08	0.26	0.18
3	0.16	0.11	0.19	0.05	0.14	0.09
4	0.09	0.05	0.10	0.03	0.07	0.04
5	0.05	0.03	0.06	0.01	0.04	0.02
6	0.29	0.28	0.13	0.12	0.19	0.06
7	0.21	0.19	0.23	0.11	0.21	0.06
8	0.31	0.21	0.29	0.05	0.15	0.[illegible]
9	0.17	0.17	0.13	0.10	0.21	0.06
10	0.16	0.09	0.24	0.08	0.25	0.15
11	0.31	0.21	0.33	0.10	0.28	0.17
12	0.05	0.06	0.06	0.03	0.10	0.06
13	0.03	0.02	0.02	0.01	0.04	0.02
14	0.01	0.01	0.01	0.01	0.02	0.01
15	0.01	*	0.01	*	0.02	0.02
16	0.18	0.10	0.19	0.05	0.13	0.07
17	0.10	0.06	0.09	0.03	0.06	0.03
18	0.05	0.02	0.05	0.01	0.03	0.01
19	0.03	0.01	0.02	*	0.01	0.01
20	0.01	0.02	0.06	0.02	0.06	0.04
21	0.04	0.03	0.08	0.02	0.07	0.05
22	0.11	0.07	0.12	0.03	0.08	0.06
23	0.17	0.10	0.19	0.05	0.13	0.10

* Wave amplitude is below significance for tabulation.

Table 32
HARBD Wave Amplification Factors
Plan 1a, Wave Angle = 157.5 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.47	0.41	0.48	0.21	0.19	0.35
2	0.39	0.30	0.36	0.11	0.21	0.22
3	0.11	0.11	0.19	0.10	0.10	0.15
4	0.06	0.06	0.11	0.06	0.05	0.07
5	0.03	0.04	0.07	0.03	0.03	0.04
6	0.32	0.27	0.33	0.10	0.21	0.12
7	0.26	0.25	0.45	0.09	0.21	0.14
8	0.34	0.15	0.38	0.04	0.12	0.14
9	0.21	0.21	0.18	0.07	0.19	0.16
10	0.18	0.12	0.31	0.05	0.17	0.25
11	0.32	0.26	0.35	0.11	0.23	0.27
12	0.05	0.06	0.08	0.03	0.08	0.09
13	0.03	0.03	0.02	0.01	0.03	0.03
14	0.01	0.02	0.02	*	0.01	0.02
15	0.02	0.01	0.01	*	0.01	0.02
16	0.12	0.15	0.20	0.10	0.09	0.13
17	0.07	0.07	0.10	0.05	0.05	0.06
18	0.03	0.02	0.05	0.02	0.02	0.03
19	0.02	0.02	0.03	0.01	0.01	0.01
20	0.01	0.03	0.06	0.03	*	0.07
21	0.02	0.03	0.07	0.04	0.05	0.08
22	0.08	0.10	0.11	0.07	0.05	0.09
23	0.11	0.16	0.16	0.15	0.08	0.14

* Wave amplitude is below significance for tabulation.

Table 33
HARBD Wave Amplification Factors
Plan 1a, Wave Angle = 180.0 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.52	0.70	0.50	0.46	0.17	0.28
2	0.32	0.44	0.37	0.30	0.09	0.24
3	0.20	0.21	0.20	0.18	0.09	0.13
4	0.10	0.12	0.12	0.10	0.05	0.07
5	0.06	0.08	0.07	0.06	0.03	0.04
6	0.14	0.19	0.35	0.12	0.04	0.18
7	0.16	0.32	0.48	0.09	0.03	0.20
8	0.20	0.25	0.39	0.18	0.03	0.14
9	0.12	0.24	0.19	0.15	0.01	0.20
10	0.06	0.23	0.31	0.19	0.03	0.23
11	0.18	0.45	0.36	0.31	0.10	0.27
12	0.06	0.07	0.08	0.06	0.03	0.10
13	0.03	0.03	0.03	0.02	0.01	0.03
14	0.01	0.02	0.02	0.01	0.01	0.02
15	*	0.01	0.01	0.01	*	0.02
16	0.21	0.27	0.21	0.18	0.09	0.13
17	0.12	0.12	0.10	0.09	0.05	0.06
18	0.04	0.05	0.05	0.05	0.02	0.03
19	0.03	0.04	0.03	0.02	0.01	0.01
20	0.03	0.06	0.06	0.06	0.03	0.06
21	0.05	0.04	0.08	0.08	0.04	0.07
22	0.13	0.13	0.12	0.15	0.05	0.08
23	0.21	0.26	0.17	0.29	0.12	0.13

* Wave amplitude is below significance for tabulation.

Table 34
HARBD Wave Amplification Factors
Plan 1a, Wave Angle = 202.5 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.89	0.88	0.51	0.58	0.28	0.27
2	0.64	0.62	0.37	0.41	0.17	0.24
3	0.31	0.28	0.20	0.22	0.11	0.13
4	0.15	0.16	0.12	0.12	0.07	0.07
5	0.08	0.11	0.07	0.07	0.04	0.04
6	0.33	0.16	0.35	0.21	0.11	0.18
7	0.41	0.36	0.48	0.15	0.08	0.20
8	0.48	0.31	0.39	0.26	0.08	0.14
9	0.32	0.19	0.19	0.24	0.10	0.20
10	0.16	0.24	0.31	0.29	0.11	0.23
11	0.43	0.45	0.36	0.42	0.20	0.27
12	0.13	0.08	0.08	0.09	0.06	0.09
13	0.05	0.01	0.03	0.03	0.02	0.03
14	0.02	0.01	0.02	0.01	0.01	0.02
15	0.01	0.01	0.01	0.01	0.01	0.02
16	0.32	0.32	0.21	0.22	0.12	0.12
17	0.18	0.15	0.10	0.11	0.06	0.06
18	0.07	0.06	0.05	0.05	0.03	0.03
19	0.04	0.05	0.03	0.02	0.01	0.01
20	0.05	0.08	0.06	0.07	0.04	0.06
21	0.07	0.08	0.08	0.09	0.05	0.07
22	0.19	0.16	0.12	0.18	0.07	0.07
23	0.31	0.29	0.18	0.36	0.17	0.12

* Wave amplitude is below significance for tabulation.

Table 35
HARBD Wave Amplification Factors
Plan 1a, Wave Angle = 225.0 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.94	0.97	0.61	0.61	0.44	0.30
2	0.82	0.81	0.46	0.43	0.30	0.29
3	0.26	0.29	0.24	0.24	0.16	0.14
4	0.13	0.18	0.13	0.13	0.10	0.07
5	0.07	0.11	0.08	0.08	0.05	0.03
6	0.56	0.32	0.34	0.30	0.25	0.11
7	0.66	0.57	0.43	0.43	0.20	0.09
8	0.70	0.42	0.48	0.48	0.15	0.19
9	0.51	0.31	0.24	0.24	0.22	0.08
10	0.25	0.38	0.38	0.39	0.22	0.21
11	0.60	0.60	0.51	0.51	0.36	0.26
12	0.19	0.11	0.09	0.09	0.11	0.10
13	0.07	0.02	0.02	0.02	0.04	0.03
14	0.02	0.01	0.01	0.01	0.02	0.02
15	0.01	0.01	0.01	0.01	0.02	0.03
16	0.28	0.34	0.24	0.23	0.17	0.12
17	0.16	0.16	0.12	0.12	0.09	0.06
18	0.06	0.07	0.06	0.06	0.04	0.02
19	0.03	0.06	0.03	0.03	0.02	0.02
20	0.04	0.08	0.08	0.08	0.06	0.06
21	*0.05*	*0.09*	*0.11*	*0.11*	0.06	0.09
22	0.16	0.16	0.17	0.17	0.08	0.11
23	0.26	0.28	0.27	0.27	0.23	0.17

* Wave amplitude is below significance for tabulation.

Table 36
HARBD Wave Amplification Factors
Plan 1a, Wave Angle = 247.5 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.74	0.60	0.61	0.44	0.25	0.30
2	0.71	0.64	0.43	0.31	0.22	0.30
3	0.13	0.25	0.24	0.16	0.11	0.15
4	0.06	0.14	0.13	0.10	0.06	0.07
5	0.03	0.09	0.08	0.05	0.03	0.03
6	0.62	0.37	0.29	0.25	0.19	0.12
7	0.51	0.48	0.43	0.20	0.21	0.09
8	0.51	0.39	0.48	0.15	0.13	0.20
9	0.44	0.19	0.24	0.22	0.19	0.08
10	0.23	0.30	0.39	0.22	0.21	0.21
11	0.49	0.40	0.51	0.36	0.25	0.26
12	0.16	0.10	0.09	0.11	0.09	0.10
13	0.06	0.02	0.02	0.04	0.03	0.03
14	0.02	0.01	0.01	0.02	0.02	0.02
15	0.01	0.01	0.01	0.02	0.02	0.03
16	0.17	0.27	0.24	0.17	0.10	0.12
17	0.08	0.12	0.12	0.09	0.05	0.06
18	0.03	0.06	0.06	0.04	0.02	0.03
19	0.02	0.04	0.03	0.02	0.01	0.02
20	0.02	0.07	0.08	0.06	0.05	0.07
21	0.02	0.08	0.11	0.07	0.06	0.09
22	0.10	0.15	0.17	0.08	0.06	0.11
23	0.10	0.26	0.28	0.23	0.10	0.18

* Wave amplitude is below significance for tabulation.

Table 37
HARBD Wave Amplification Factors
Plan 1a, Wave Angle = 270.0 deg

Basin	Wave Period, sec 9	11	13	15	17	20
1	0.80	0.53	0.61	0.44	0.25	0.30
2	0.74	0.52	0.43	0.31	0.22	0.30
3	0.15	0.22	0.24	0.16	0.11	0.15
4	0.07	0.13	0.13	0.10	0.06	0.07
5	0.04	0.08	0.08	0.05	0.03	0.03
6	0.63	0.36	0.29	0.25	0.19	0.12
7	0.52	0.47	0.43	0.20	0.21	0.09
8	0.53	0.38	0.48	0.15	0.13	0.20
9	0.45	0.18	0.24	0.22	0.19	0.08
10	0.24	0.29	0.38	0.22	0.21	0.21
11	0.51	0.35	0.51	0.36	0.25	0.26
12	0.16	0.09	0.09	0.11	0.09	0.10
13	0.06	0.03	0.02	0.04	0.03	0.03
14	0.02	0.02	0.01	0.02	0.02	0.02
15	0.01	0.01	0.01	0.02	0.02	0.03
16	0.18	0.24	0.24	0.17	0.10	0.13
17	0.09	0.11	0.12	0.09	0.05	0.06
18	0.03	0.05	0.06	0.04	0.02	0.03
19	0.02	0.04	0.03	0.02	0.01	0.02
20	0.03	0.06	0.08	0.06	0.05	0.07
21	0.03	0.08	0.11	0.07	0.06	0.09
22	0.12	0.13	0.17	0.08	0.06	0.11
23	0.11	0.22	0.28	0.23	0.10	0.18

* Wave amplitude is below significance for tabulation.

Table 38
HARBD Wave Amplification Factors
Plan 1b, Wave Angle = 135.0 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.54	0.40	0.44	0.09	0.29	0.20
2	0.45	0.27	0.25	0.09	0.24	0.18
3	0.15	0.11	0.17	0.05	0.14	0.09
4	0.09	0.05	0.10	0.03	0.07	0.04
5	0.05	0.03	0.06	0.02	0.04	0.02
6	0.29	0.28	0.13	0.11	0.22	0.06
7	0.20	0.19	0.28	0.10	0.22	0.08
8	0.30	0.22	0.31	0.08	0.09	0.13
9	0.09	0.22	0.12	0.11	0.22	0.05
10	0.19	0.04	0.24	0.05	0.26	0.16
11	0.32	0.26	0.44	0.11	0.37	0.21
12	0.06	0.07	0.09	0.03	0.13	0.08
13	0.04	0.03	0.03	0.01	0.04	0.03
14	0.01	0.01	0.02	0.01	0.02	0.02
15	0.02	0.01	0.01	*	0.02	0.02
16	0.17	0.10	0.18	0.05	0.13	0.07
17	0.10	0.06	0.09	0.03	0.07	0.03
18	0.04	0.02	0.04	0.01	0.03	0.02
19	0.02	0.01	0.02	*	0.01	0.01
20	0.01	0.02	0.05	0.02	0.06	0.04
21	0.03	0.03	0.07	0.02	0.08	0.05
22	0.11	0.07	0.12	0.03	0.08	0.07
23	0.17	0.10	0.20	0.05	0.11	0.12

* Wave amplitude is below significance for tabulation.

Table 39
HARBD Wave Amplification Factors
Plan 1b, Wave Angle = 157.5 deg

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.48	0.42	0.47	0.21	0.18	0.37
2	0.42	0.31	0.35	0.11	0.21	0.21
3	0.10	0.12	0.17	0.10	0.09	0.16
4	0.05	0.05	0.10	0.06	0.05	0.08
5	0.03	0.04	0.06	0.03	0.03	0.04
6	0.32	0.30	0.35	0.09	0.25	0.12
7	0.24	0.26	0.52	0.08	0.17	0.18
8	0.32	0.18	0.38	0.07	0.13	0.09
9	0.11	0.28	0.18	0.08	0.21	0.15
10	0.22	0.06	0.25	0.06	0.15	0.28
11	0.33	0.32	0.46	0.14	0.29	0.35
12	0.06	0.09	0.11	0.03	0.10	0.12
13	0.04	0.04	0.04	0.01	0.03	0.04
14	0.01	0.02	0.02	*	0.02	0.02
15	0.02	0.02	0.01	*	0.01	0.02
16	0.12	0.15	0.19	0.10	0.09	0.14
17	0.07	0.07	0.09	0.05	0.04	0.07
18	0.03	0.02	0.04	0.02	0.02	0.03
19	0.01	0.02	0.03	0.01	0.01	0.01
20	0.01	0.03	0.05	0.03	0.04	0.07
21	0.02	0.03	0.06	0.04	0.05	0.09
22	0.09	0.11	0.11	0.07	0.04	0.10
23	0.11	0.16	0.17	0.15	0.06	0.15

* Wave amplitude is below significance for tabulation.

Table 40

HARBD Wave Amplification Factors

Plan 1b, Wave Angle = 180.0 deg

	Wave Period, sec					
Basin	9	11	13	15	17	20
1	0.50	0.69	0.49	0.47	0.18	0.28
2	0.29	0.42	0.36	0.31	0.10	0.23
3	0.21	0.20	0.18	0.18	0.09	0.14
4	0.10	0.11	0.10	0.10	0.05	0.07
5	0.06	0.08	0.06	0.06	0.03	0.04
6	0.14	0.22	0.37	0.12	0.04	0.21
7	0.16	0.33	0.54	0.11	0.04	0.21
8	0.22	0.26	0.40	0.20	0.05	0.09
9	0.16	0.32	0.20	0.14	0.02	0.21
10	0.09	0.11	0.23	0.21	0.06	0.25
11	0.28	0.56	0.48	0.39	0.13	0.35
12	0.07	0.10	0.12	0.08	0.04	0.12
13	0.04	0.04	0.04	0.02	0.01	0.04
14	0.01	0.03	0.02	0.01	0.01	0.02
15	0.01	0.02	0.01	*	*	0.02
16	0.20	0.26	0.19	0.19	0.09	0.13
17	0.12	0.11	0.09	0.09	0.05	0.06
18	0.05	0.04	0.05	0.05	0.02	0.03
19	0.03	0.04	0.03	0.02	0.01	0.01
20	0.03	0.05	0.05	0.06	0.03	0.06
21	0.05	0.04	0.07	0.08	0.04	0.07
22	0.13	0.14	0.12	0.15	0.05	0.08
23	0.21	0.27	0.18	0.31	0.12	0.11

* Wave amplitude is below significance for tabulation.

Table 41 HARBD Wave Amplification Factors Plan 1b, Wave Angle = 202.5 deg						
	Wave Period, sec					
Basin	9	11	13	15	17	20
1	0.85	0.91	0.50	0.59	0.28	0.28
2	0.58	0.64	0.36	0.42	0.18	0.23
3	0.33	0.28	0.18	0.21	0.11	0.14
4	0.16	0.17	0.11	0.12	0.07	0.07
5	0.09	0.11	0.06	0.07	0.04	0.03
6	0.34	0.15	0.37	0.19	0.12	0.21
7	0.43	0.39	0.55	0.15	0.07	0.21
8	0.51	0.36	0.40	0.29	0.09	0.09
9	0.39	0.27	0.20	0.23	0.10	0.21
10	0.17	0.09	0.22	0.30	0.13	0.25
11	0.60	0.59	0.48	0.52	0.25	0.35
12	0.16	0.11	0.12	0.10	0.07	0.12
13	0.08	0.03	0.04	0.03	0.02	0.04
14	0.03	0.02	0.02	0.01	0.01	0.02
15	0.02	0.02	0.02	0.01	0.01	0.02
16	0.31	0.32	0.19	0.22	0.12	0.12
17	0.19	0.15	0.09	0.11	0.06	0.06
18	0.07	0.06	0.05	0.06	0.03	0.03
19	0.04	0.05	0.03	0.03	0.01	0.01
20	0.05	0.08	0.05	0.07	0.04	0.06
21	0.08	0.08	0.07	0.09	0.05	0.07
22	0.20	0.15	0.12	0.18	0.07	0.08
23	0.32	0.27	0.19	0.38	0.18	0.11

* Wave amplitude is below significance for tabulation.

Table 42
HARBD Wave Amplification Factors
Plan 1b, Wave Angle = 225.0

Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.89	1.02	0.61	0.61	0.45	0.31
2	0.75	0.83	0.50	0.39	0.32	0.29
3	0.30	0.30	0.22	0.22	0.16	0.14
4	0.14	0.18	0.12	0.12	0.10	0.07
5	0.07	0.12	0.07	0.07	0.05	0.03
6	0.58	0.30	0.33	0.32	0.26	0.10
7	0.69	0.61	0.50	0.51	0.16	0.13
8	0.72	0.49	0.51	0.51	0.18	0.18
9	0.57	0.39	0.23	0.23	0.23	0.06
10	0.21	0.18	0.32	0.33	0.21	0.23
11	0.79	0.77	0.66	0.66	0.43	0.33
12	0.22	0.14	0.13	0.13	0.12	0.13
13	0.11	0.04	0.04	0.04	0.04	0.04
14	0.04	0.03	0.03	0.03	0.02	0.03
15	0.02	0.02	0.02	0.02	0.01	0.03
16	0.27	0.35	0.23	0.23	0.18	0.12
17	0.16	0.16	0.11	0.11	0.09	0.06
18	0.06	0.07	0.06	0.06	0.04	0.03
19	0.04	0.06	0.03	0.03	0.02	0.02
20	0.04	0.08	0.07	0.07	0.06	0.06
21	0.06	0.09	0.10	0.10	0.06	0.09
22	0.17	0.15	0.16	0.16	0.08	0.11
23	0.27	0.26	0.29	0.29	0.24	0.20

* Wave amplitude is below significance for tabulation.

Table 43 HARBD Wave Amplification Factors Plan 1b, Wave Angle = 247.5 deg						
Basin	Wave Period, sec					
	9	11	13	15	17	20
1	0.74	0.58	0.62	0.45	0.25	0.31
2	0.71	0.70	0.39	0.33	0.21	0.30
3	0.14	0.25	0.22	0.16	0.12	0.14
4	0.05	0.14	0.13	0.10	0.06	0.07
5	0.02	0.09	0.07	0.05	0.03	0.03
6	0.62	0.36	0.31	0.26	0.22	0.10
7	0.50	0.52	0.50	0.16	0.21	0.13
8	0.55	0.40	0.51	0.18	0.09	0.18
9	0.53	0.23	0.23	0.23	0.21	0.06
10	0.15	0.17	0.33	0.21	0.22	0.23
11	0.62	0.55	0.66	0.43	0.33	0.33
12	0.18	0.13	0.13	0.12	0.11	0.13
13	0.08	0.03	0.04	0.04	0.04	0.04
14	0.03	0.02	0.03	0.02	0.02	0.03
15	0.02	0.01	0.02	0.01	0.02	0.04
16	0.15	0.26	0.23	0.18	0.11	0.12
17	0.08	0.12	0.11	0.09	0.05	0.06
18	0.02	0.06	0.06	0.04	0.02	0.03
19	0.01	0.04	0.03	0.02	0.01	0.02
20	0.02	0.07	0.07	0.06	0.05	0.06
21	0.03	0.09	0.10	0.06	0.06	0.09
22	0.11	0.18	0.16	0.08	0.07	0.12
23	0.10	0.27	0.29	0.24	0.09	0.21

* Wave amplitude is below significance for tabulation.

Table 44
HARBD Wave Amplification Factors
Plan 1b, Wave Angle = 270.0 deg

	Wave Period, sec					
Basin	9	11	13	15	17	20
1	0.79	0.51	0.61	0.45	0.25	0.31
2	0.74	0.56	0.39	0.33	0.21	0.30
3	0.15	0.21	0.22	0.16	0.12	0.14
4	0.06	0.12	0.12	0.10	0.06	0.07
5	0.04	0.07	0.07	0.05	0.03	0.03
6	0.63	0.36	0.31	0.26	0.22	0.10
7	0.50	0.52	0.50	0.16	0.21	0.13
8	0.57	0.38	0.51	0.18	0.09	0.18
9	0.55	0.21	0.23	0.23	0.21	0.06
10	0.15	0.17	0.33	0.21	0.22	0.23
11	0.64	0.48	0.66	0.43	0.33	0.33
12	0.19	0.12	0.13	0.12	0.11	0.13
13	0.08	0.03	0.04	0.04	0.04	0.04
14	0.03	0.02	0.03	0.02	0.02	0.03
15	0.02	0.01	0.02	0.01	0.02	0.04
16	0.17	0.23	0.23	0.18	0.11	0.12
17	0.09	0.10	0.11	0.09	0.05	0.06
18	0.03	0.05	0.06	0.04	0.02	0.03
19	0.02	0.03	0.03	0.02	0.01	0.02
20	0.02	0.06	0.07	0.06	0.05	0.06
21	0.03	0.08	0.10	0.06	0.06	0.09
22	0.12	0.16	0.16	0.08	0.07	0.12
23	0.12	0.24	0.29	0.24	0.09	0.21

* Wave amplitude is below significance for tabulation.

Table 45
HARBD-SHALWV Wave Heights Exceeding HQUSACE Criteria*
(Deepwater Wave Conditions)

Direction (deg)	Period (sec)	Height (ft)	Deepwater Height (ft)	HARBD Amp. factor	SHALWV Height (ft)	Basin Num. #
Existing Plan - 1 ft Criteria						
135.0	*					
157.5	13	1.02	3.00	0.59	1.73	4
	15	1.06	4.00	0.66	1.56	4
180.0	13	1.11	5.00	0.47	2.37	4
	15	1.10	3.00	0.76	1.45	7
	17	1.09	3.00	0.79	1.38	4
202.5	11	1.05	4.00	0.64	1.64	5
	13	1.08	4.00	0.70	1.55	4
	15	1.02	6.00	0.47	2.04	4
	17	1.10	4.00	0.78	1.41	4
225.0	9	1.09	4.00	0.76	1.45	9
	13	1.01	6.00	0.58	1.74	9
	15	1.03	8.00	0.47	2.20	7
	17	1.04	7.00	0.57	1.81	7
247.5	9	1.11	7.00	0.89	1.25	4
270.0	*					
Existing Plan - 2 ft Criteria						
135.0	*					
157.5	*					
180.0	15	2.02	3.00	1.40	1.45	1
	17	2.07	3.00	1.50	1.38	1
202.5	11	2.05	4.00	1.24	1.64	1
	17	2.04	4.00	1.45	1.41	1
225.0	9	2.01	4.00	1.39	1.45	1
247.5	9	2.07	8.00	1.26	1.64	1
270.0*						

* Deepwater wave heights between 1-9 ft do not exceed HQUSACE criteria for this condition.

Table 46
HARBD-SHALWV Wave Heights Exceeding HQUSACE Criteria*
(Deepwater Wave Conditions)

Direction (deg)	Period (sec)	Height (ft)	Deepwater Height (ft)	HARBD Amp. factor	SHALWV Height (ft)	Basin Num. #
Proposed Plan 1 - 1 ft Criteria						
135.0	*					
157.5	*					
180.0	13	1.01	5.00	0.43	2.37	11
202.5	*					
225.0	13 15	1.08 1.03	7.00 8.00	0.53 0.47	2.04 2.20	6 8
247.5	*					
270.0*						
Proposed Plan 1 - 2 ft Criteria						
135.0	*					
157.5	*					
180.0	*					
202.5	*					
225.0	*					
247.5	*					
270.0	*					

* Deepwater wave heights between 1-9 ft do not exceed HQUSACE criteria for this condition.

Table 47
HARBD-SHALWV Wave Heights Exceeding HQUSACE Criteria*
(Deepwater Wave Conditions)

Direction (deg)	Period (sec)	Height (ft)	Deepwater Height (ft)	HARBD Amp. factor	SHALWV Height (ft)	Basin Num. #
Proposed Plan 2 - 1 ft Criteria						
135.0	*					
157.5	11	1.22	4.00	0.70	1.74	23
180.0	9	1.17	3.00	0.68	1.71	7
	11	1.47	3.00	0.91	1.62	7
	13	1.04	4.00	0.51	2.04	7
	20	1.03	5.00	0.56	1.84	8
202.5	9	1.04	5.00	0.51	2.04	23
	11	1.17	6.00	0.54	2.17	7
	13	1.18	4.00	0.80	1.48	7
	20	1.01	4.00	0.80	1.26	7
225.0	9	1.10	6.00	0.56	1.97	7
	11	1.08	7.00	0.50	2.17	7
247.5	*					
270.0	*					
Proposed Plan 2 - 2 ft Criteria						
135.0	*					
157.5	11	2.09	4.00	1.20	1.74	1
180.0	9	2.68	3.00	1.56	1.72	1
	11	2.35	3.00	1.45	1.62	1
	13	2.37	4.00	1.16	2.04	1
	17	2.05	5.00	0.94	2.18	1
	20	2.04	6.00	0.91	2.24	1
202.5	13	2.29	4.00	1.55	1.48	1
	20	2.07	5.00	1.51	1.37	1
225.0	9	2.03	7.00	0.87	2.34	1
	11	2.04	7.00	0.94	2.17	1
247.5	*					
270.0*						

* Deepwater wave heights between 1-9 ft do not exceed HQUSACE criteria for this condition.

Table 48
HARBD-SHALWV Wave Heights Exceeding HQUSACE Criteria*
(Deepwater Wave Conditions)

Direction (deg)	Period (sec)	Height (ft)	Deepwater Height (ft)	HARBD Amp. factor	SHALWV Height (ft)	Basin Num. #
Proposed Plan 3 - 1 ft Criteria						
135.0	*					
157.5	*					
180.0	*					
202.5	*					
225.0	*					
247.5	*					
270.0	*					
Proposed Plan 3 - 2 ft Criteria						
135.0	*					
157.5	*					
180.0	*					
202.5	*					
225.0	*					
247.5	*					
270.0	*					

* Deepwater wave heights between 1-9 ft do not exceed HQUSACE criteria for this condition.

Table 49
HARBD-SHALWV Wave Heights Exceeding HQUSACE Criteria*
(Deepwater Wave Conditions)

Direction (deg)	Period (sec)	Height (ft)	Deepwater Height (ft)	HARBD Amp. factor	SHALWV Height (ft)	Basin Num. #
Proposed Plan 1a - 1 ft Criteria						
135.0	*					
157.5	*					
180.0	11	1.13	5.00	0.45	2.51	11
	13	1.13	5.00	0.48	2.37	7
202.5	9	1.11	6.00	0.48	2.29	8
	13	1.03	6.00	0.48	2.17	7
	15	1.13	8.00	0.42	2.68	11
225.0	9	1.01	4.00	0.70	1.45	8
	11	1.10	6.00	0.60	1.83	11
	13	1.19	8.00	0.51	2.34	11
	15	1.12	8.00	0.51	2.20	11
247.5	9	1.02	8.00	0.62	1.64	6
270.0	*					
Proposed Plan 1a - 2 ft Criteria						
135.0	*					
157.5	*					
180.0	*					
202.5	9	2.03	6.00	0.89	2.29	1
225.0	9	2.19	7.00	0.94	2.34	1
	11	2.11	7.00	0.97	2.17	1
247.5	*					
270.0	*					

* Deepwater wave heights tested do not exceed HQUSACE criteria for this condition.

Table 50
HARBD-SHALWV Wave Heights Exceeding HQUSACE Criteria*
(Deepwater Wave Conditions)

Direction (deg)	Period (sec)	Height (ft)	Deepwater Height (ft)	HARBD Amp. factor	SHALWV Height (ft)	Basin Num. #
Proposed Plan 1b - 1 ft Criteria						
135.0	*					
157.5	13	1.02	5.00	0.52	1.97	7
180.0	11	1.19	4.00	0.56	2.13	11
	13	1.11	4.00	0.55	2.04	7
202.5	9	1.01	4.00	0.60	1.69	11
	11	1.11	5.00	0.60	1.86	11
	13	1.18	6.00	0.55	2.17	7
	15	1.09	5.00	0.65	1.67	11
225.0	9	1.15	4.00	0.79	1.45	11
	11	1.04	4.00	0.77	1.35	11
	13	1.54	8.00	0.66	2.34	11
	15	1.09	6.00	0.66	1.64	11
247.5	9	1.02	8.00	0.62	1.64	6
	13	1.04	8.00	0.67	1.57	11
270.0	*					
Proposed Plan 1b - 2 ft Criteria						
135.0	*					
157.5	*					
180.0	*					
202.5	9	2.33	7.00	0.85	2.75	1
225.0	9	2.08	7.00	0.89	2.34	1
	11	2.21	7.00	1.02	2.17	1
247.5	*					
270.0	*					

* Deepwater wave heights tested do not exceed HQUSACE criteria for this condition.

Table 51
Percent Occurrence of Wave Heights Versus Direction*
Existing Plan - Wave Heights Exceeding 1 ft

Wave Height ft	Wave Direction, deg (from which waves approach)							
	135.0	157.5	180.0	202.5	225.0	247.5	270.0	Total
0.00-1.00	.	.	.	.	.	.	.	0.00
1.01-2.00	.	.	.	.	.	.	.	0.00
2.01-3.00	.	0.01	0.45	.	.	.	.	0.46
3.01-4.00	.	0.01	0.18	1.55	1.02	.	.	2.76
4.01-5.00	.	.	0.03	0.70	0.90	.	.	1.63
5.01-6.00	.	.	0.02	1.05	2.79	.	.	3.86
6.01-7.00	.	.	.	1.68	2.06	0.34	.	4.08
7.01-8.00	.	.	*	0.77	2.89	0.36	.	4.03
8.01-9.00	.	.	.	0.19	2.34	0.13	.	2.66
9.01 +	.	.	.	.	.	1.25	0.65	1.90
TOTAL	0.00	0.02	0.69	5.94	12.00	2.08	0.65	21.38

* Percent occurrence is below significance for tabulation.

Table 52
Percent Occurrence of Wave Heights Versus Direction*
Existing Plan - Wave Heights Exceeding 2 ft

Wave Height ft	Wave Direction, deg (from which waves approach)							
	135.0	157.5	180.0	202.5	225.0	247.5	270.0	Total
0.00-1.00	.	.	.	.	.	.	.	0.00
1.01-2.00	.	.	.	.	.	.	.	0.00
2.01-3.00	.	.	0.45	.	.	.	.	0.45
3.01-4.00	.	.	0.18	1.18	1.02	.	.	2.38
4.01-5.00	.	.	*	0.61	0.90	.	.	1.51
5.01-6.00	.	.	0.02	0.21	0.49	.	.	0.72
6.01-7.00	.	.	.	0.63	0.34	.	.	0.97
7.01-8.00	.	.	*	0.26	0.41	.	.	0.77
8.01-9.00	.	.	.	.	0.88	0.13	.	1.01
9.01 +	.	.	.	.	.	1.25	0.65	1.68
TOTAL	0.00	0.00	0.65	2.89	4.04	1.38	0.65	9.61

* Percent occurrence is below significance for tabulation.

Table 53
Percent Occurrence of Wave Heights Versus Direction*
Plan 1 - Wave Heights Exceeding 1 ft

Wave Height ft	Wave Direction, deg (from which waves approach)							
	135.0	157.5	180.0	202.5	225.0	247.5	270.0	Total
3.01-4.00	.	.	.	.	.	.	.	0.00
4.01-5.00	.	.	0.03	.	.	.	.	0.03
5.01-6.00	.	.	.	.	.	.	.	0.00
6.01-7.00	.	.	.	.	1.42	.	.	1.42
7.01-8.00	.	.	.	.	1.74	.	.	1.74
8.01-9.00	.	.	.	.	0.99	.	.	0.99
9.01 +	.	.	.	.	.	1.25	0.65	1.90
TOTAL	0.00	0.00	0.03	0.00	4.15	1.25	0.65	6.08

* Percent occurrence is below significance for tabulation.

Table 54
Percent Occurrence of Wave Heights Versus Direction*
Plan 1 - Wave Heights Exceeding 2 ft

Wave Height ft	Wave Direction, deg (from which waves approach)							
	135.0	157.5	180.0	202.5	225.0	247.5	270.0	Total
2.01-3.00	.	.	.	.	.	.	.	0.00
3.01-4.00	.	.	.	.	.	.	.	0.00
4.01-5.00	.	.	.	.	.	.	.	0.00
5.01-6.00	.	.	.	.	.	.	.	0.00
6.01-7.00	.	.	.	.	.	.	.	0.00
7.01-8.00	.	.	.	.	.	.	.	0.00
8.01-9.00	.	.	.	.	.	.	.	0.00
9.01 +	.	.	.	.	.	1.25	0.65	1.90
TOTAL	0.00	0.00	0.00	0.00	0.00	1.25	0.65	1.90

* Percent occurrence is below significance for tabulation.

Table 55
Percent Occurrence of Wave Heights Versus Direction*
Plan 2 - Wave Heights Exceeding 1 ft

Wave Height ft	Wave Direction, deg (from which waves approach)							
	135.0	157.5	180.0	202.5	225.0	247.5	270.0	Total
2.01-3.00	.	.	0.32	.	.	.	.	0.32
3.01-4.00	.	0.01	0.06	2.09	.	.	.	2.16
4.01-5.00	.	.	0.03	1.40	.	.	.	1.43
5.01-6.00	.	.	.	0.91	2.79	.	.	3.70
6.01-7.00	.	.	*	1.18	1.91	.	.	3.09
7.01-8.00	.	.	0.09	0.70	2.11	.	.	2.90
8.01-9.00	.	.	.	0.19	1.97	.	.	2.16
9.01 +	.	.	.	.	.	1.25	0.65	1.90
TOTAL	0.00	0.01	0.50	6.47	8.78	1.25	0.65	17.66

* Percent occurrence is below significance for tabulation.

Table 56
Percent Occurrence of Wave Heights Versus Direction*
Plan 2 - Wave Heights Exceeding 2 ft

Wave Height ft	Wave Direction, deg (from which waves approach)							
	135.0	157.5	180.0	202.5	225.0	247.5	270.0	Total
2.01-3.00	.	.	0.32	.	.	.	.	0.32
3.01-4.00	.	0.01	0.06	2.09	.	.	.	2.16
4.01-5.00	.	.	0.03	1.26	.	.	.	1.29
5.01-6.00	.	.	.	0.66	.	.	.	0.66
6.01-7.00	.	.	*	1.04	0.50	.	.	1.54
7.01-8.00	.	.	0.09	0.51	1.09	.	.	1.69
8.01-9.00	.	.	.	0.19	1.52	.	.	1.71
9.01 +	.	.	.	.	.	1.25	0.65	1.90
TOTAL	0.00	0.01	0.50	5.75	3.11	1.25	0.65	11.27

* Percent occurrence is below significance for tabulation.

Table 57
Percent Occurrence of Wave Heights Versus Direction*
Plan 3 - Wave Heights Exceeding 1 ft

Wave Height ft	Wave Direction, deg (from which waves approach)							
	135.0	157.5	180.0	202.5	225.0	247.5	270.0	Total
2.01-3.00	.	.	.	.	.	.	.	0.00
3.01-4.00	.	.	.	.	.	.	.	0.00
4.01-5.00	.	.	.	.	.	.	.	0.00
5.01-6.00	.	.	.	.	.	.	.	0.00
6.01-7.00	.	.	.	.	.	.	.	0.00
7.01-8.00	.	.	.	.	.	.	.	0.00
8.01-9.00	.	.	.	.	.	.	.	0.00
9.01 +	.	.	.	.	.	1.25	0.65	1.90
TOTAL	0.00	0.00	0.00	0.00	0.00	1.25	0.65	1.90

* Percent occurrence is below significance for tabulation.

Table 58
Percent Occurrence of Wave Heights Versus Direction*
Plan 3 - Wave Heights Exceeding 2 ft

Wave Height ft	Wave Direction, deg (from which waves approach)							
	135.0	157.5	180.0	202.5	225.0	247.5	270.0	Total
2.01-3.00	.	.	.	.	.	.	.	0.00
3.01-4.00	.	.	.	.	.	.	.	0.00
4.01-5.00	.	.	.	.	.	.	.	0.00
5.01-6.00	.	.	.	.	.	.	.	0.00
6.01-7.00	.	.	.	.	.	.	.	0.00
7.01-8.00	.	.	.	.	.	.	.	0.00
8.01-9.00	.	.	.	.	.	.	.	0.00
9.01 +	.	.	.	.	.	1.25	0.65	1.90
TOTAL	0.00	0.00	0.00	0.00	0.00	1.25	0.65	1.90

* Percent occurrence is below significance for tabulation.

Table 59
Percent Occurrence of Wave Heights Versus Direction*
Plan 1a - Wave Heights Exceeding 1 ft

Wave Height ft	Wave Direction, deg (from which waves approach)							
	135.0	157.5	180.0	202.5	225.0	247.5	270.0	Total
3.01-4.00	.	.	.	.	.	.	.	0.00
4.01-5.00	.	.	0.03	.	0.89	.	.	0.92
5.01-6.00	.	.	.	0.10	1.32	.	.	1.42
6.01-7.00	.	.	.	0.08	0.49	.	.	0.58
7.01-8.00	.	.	.	0.59	1.75	.	.	2.34
8.01-9.00	.	.	.	0.19	2.51	0.13	.	2.84
9.01 +	.	.	.	.	.	1.25	0.65	1.90
TOTAL	0.00	0.00	0.03	0.97	6.97	1.38	0.65	10.00

* Percent occurrence is below significance for tabulation.

Table 60
Percent Occurrence of Wave Heights Versus Direction*
Plan 1a - Wave Heights Exceeding 2 ft

Wave Height ft	Wave Direction, deg (from which waves approach)							
	135.0	157.5	180.0	202.5	225.0	247.5	270.0	Total
2.01-3.00	.	.	.	.	.	.	.	0.00
3.01-4.00	.	.	.	.	.	.	.	0.00
4.01-5.00	.	.	.	.	.	.	.	0.00
5.01-6.00	.	.	.	0.01	.	.	.	0.01
6.01-7.00	.	.	.	0.08	0.27	.	.	0.35
7.01-8.00	.	.	.	0.09	1.09	.	.	1.18
8.01-9.00	.	.	.	.	1.52	.	.	1.52
9.01 +	.	.	.	.	.	1.25	0.65	1.90
TOTAL	0.00	0.00	0.00	0.19	2.88	1.25	0.65	4.96

* Percent occurrence is below significance for tabulation.

Table 61
Percent Occurrence of Wave Heights Versus Direction*
Plan 1b - Wave Heights Exceeding 1 ft

Wave Height ft	Wave Direction, deg (from which waves approach)							
	135.0	157.5	180.0	202.5	225.0	247.5	270.0	Total
3.01-4.00	.	.	0.02	.	0.88	.	.	0.90
4.01-5.00	.	.	0.03	1.15	2.53	.	.	3.71
5.01-6.00	.	.	.	0.90	2.36	.	.	3.26
6.01-7.00	.	.	.	1.12	1.64	.	.	2.77
7.01-8.00	.	.	.	0.59	2.83	0.07	.	3.50
8.01-9.00	.	.	.	0.19	2.51	0.14	.	2.85
9.01 +	.	.	.	.	.	1.25	0.65	1.90
TOTAL	0.00	0.00	0.05	3.96	12.76	1.47	0.65	18.89

* Percent occurrence is below significance for tabulation.

Table 62
Percent Occurrence of Wave Heights Versus Direction*
Plan 1b - Wave Heights Exceeding 2 ft

Wave Height ft	Wave Direction, deg (from which waves approach)							
	135.0	157.5	180.0	202.5	225.0	247.5	270.0	Total
2.01-3.00	.	.	.	.	.	.	.	0.00
3.01-4.00	.	.	.	.	.	.	.	0.00
4.01-5.00	.	.	.	.	.	.	.	0.00
5.01-6.00	.	.	.	.	.	.	.	0.00
6.01-7.00	.	.	.	0.07	0.20	.	.	0.27
7.01-8.00	.	.	.	0.09	1.09	.	.	1.18
8.01-9.00	.	.	.	.	1.52	.	.	1.52
9.01 +	.	.	.	.	.	1.25	0.65	1.90
TOTAL	0.00	0.00	0.00	0.16	2.81	1.25	0.65	4.87

* Percent occurrence is below significance for tabulation.

Table 63
Summary of Percent Occurrence of Wave Heights

Location	Percent of Time Criterion is Exceeded						
	HQUSACE Criterion	Existing	Plan 1	Plan 2	Plan 3	Plan 1a	Plan 1b
Berthing areas (1 ft criterion)	< 10.0	21.4	6.1	17.7	2.0	10.0	18.9
Entrance Channel (2 ft criterion)	< 10.0	9.6	2.0	11.3	2.0	5.0	4.9

Appendix A
Offshore Wave Climate Percent Occurrence Tables

Table A-1
Percent Occurrence of Height and Period by Direction
Wave Direction = 135.0 deg (from which waves approach)

Wave Height ft	Peak Period (sec)						
	9	11	13	15	17	20	Total
0.00-1.00	.	.	.	.	.	.	0.00
1.01-2.00	.	.	.	.	*	*	*
2.01-3.00	.	.	.	.	*	.	*
3.01-4.00	.	.	.	.	.	.	0.00
4.01-5.00	.	.	.	.	.	.	0.00
5.01-6.00	.	.	.	.	.	.	0.00
6.01-7.00	.	.	.	.	.	.	0.00
7.01-8.00	.	.	.	.	.	.	0.00
8.01-9.00	.	.	.	.	.	.	0.00
9.01 +	.	.	.	.	.	.	0.00
Total	0.00	0.00	0.00	0.00	*	*	0.01

* Percent occurrence is below table resolution.

Table A-2
Percent Occurrence of Height and Period by Direction
Wave Direction = 157.5 deg (from which waves approach)

Wave Height ft	Peak Period (sec)						
	9	11	13	15	17	20	Total
0.00-1.00	.	.	.	.	.	.	0.00
1.01-2.00	.	.	.	*	0.01	0.02	0.03
2.01-3.00	.	.	0.03	0.01	0.03	*	0.07
3.01-4.00	.	.	0.01	.	.	.	0.01
4.01-5.00	.	.	.	.	.	.	0.00
5.01-6.00	.	.	.	.	.	.	0.00
6.01-7.00	.	.	.	.	.	.	0.00
7.01-8.00	.	.	.	.	.	.	0.00
8.01-9.00	.	.	.	.	.	.	0.00
9.01 +	.	.	.	.	.	.	0.00
Total	0.00	0.00	0.04	0.01	0.04	0.02	0.11

* Percent occurrence is below table resolution.

Table A-3
Percent Occurrence of Height and Period by Direction
Wave Direction = 180.0 deg (from which waves approach)

Wave Height ft	Peak Period (sec)						
	9	11	13	15	17	20	Total
0.00-1.00	.	.	.	*	*	0.01	0.01
1.01-2.00	0.01	0.02	0.03	0.14	0.52	0.19	0.91
2.01-3.00	0.09	0.16	0.07	0.06	0.39	0.09	0.86
3.01-4.00	0.03	0.02	.	*	0.18	0.04	0.28
4.01-5.00	.	.	0.03	.	*	*	0.04
5.01-6.00	.	.	.	.	0.02	.	0.02
6.01-7.00	.	.	.	.	.	*	*
7.01-8.00	0.09	.	.	.	*	.	0.09
8.01-9.00	.	.	.	.	.	.	0.00
9.01 +	.	.	.	.	.	.	0.00
Total	0.22	0.20	0.13	0.21	1.12	0.33	2.21

* Percent occurrence is below table resolution.

Table A-4
Percent Occurrence of Height and Period by Direction
Wave Direction = 202.5 deg (from which waves approach)

Wave Height ft	Peak Period (sec)						
	9	11	13	15	17	20	Total
2.01-3.00	1.18	0.66	0.51	1.70	0.90	0.39	5.34
3.01-4.00	0.47	0.07	0.37	2.09	1.12	0.14	4.26
4.01-5.00	0.15	.	0.10	1.25	0.61	0.17	2.28
5.01-6.00	0.07	.	0.18	0.66	0.21	*	1.13
6.01-7.00	0.08	.	.	1.04	0.63	0.06	1.81
7.01-8.00	0.09	.	.	0.50	0.26	0.11	0.96
8.01-9.00	.	.	.	0.19	.	.	0.19
9.01 +	.	.	.	.	.	.	0.00
Total	2.32	0.80	1.53	9.25	4.76	1.30	19.96

* Percent occurrence is below table resolution.

Table A-5 Percent Occurrence of Height and Period by Direction Wave Direction = 225.0 deg (from which waves approach)							
Wave Height ft	Peak Period (sec)						
	9	11	13	15	17	20	Total
2.01-3.00	1.46	2.92	4.31	1.46	0.84	0.06	11.05
3.01-4.00	1.02	2.37	5.44	2.05	0.68	0.04	11.60
4.01-5.00	0.90	1.63	2.82	1.98	1.24	0.06	8.63
5.01-6.00	0.49	1.39	2.30	0.81	0.15	*	5.14
6.01-7.00	0.34	0.16	1.41	1.15	0.30	0.02	3.38
7.01-8.00	0.41	0.68	1.02	0.73	0.73	0.07	3.64
8.01-9.00	0.88	0.64	0.45	0.54	0.48	0.01	3.00
9.01+	.	.	.	.	.	.	0.00
Total	6.32	10.90	19.38	9.32	4.56	0.30	50.78

* Percent occurrence is below table resolution.

Table A-6 Percent Occurrence of Height and Period by Direction Wave Direction = 247.5 deg (from which waves approach)							
Wave Height ft	Peak Period (sec)						
	9	11	13	15	17	20	Total
2.01-3.00	0.73	2.22	0.78	0.31	0.08	0.04	4.16
3.01-4.00	0.64	1.87	0.69	0.51	0.08	0.02	3.81
4.01-5.00	0.35	1.22	0.38	0.31	0.01	0.01	2.28
5.01-6.00	0.55	0.68	0.06	0.17	0.05	0.01	1.52
6.01-7.00	0.34	0.41	.	0.18	0.03	*	0.96
7.01-8.00	0.36	0.28	0.17	*	0.01	.	0.83
8.01-9.00	0.13	0.07	0.01	.	.	.	0.21
9.01+	1.12	0.06	.	0.07	.	*	1.25
Total	4.40	7.52	2.43	1.63	0.29	0.10	16.37

* Percent occurrence is below table resolution.

Table A-7
Percent Occurrence of Height and Period by Direction
Wave Direction = 270.0 deg (from which waves approach)

Wave Height ft	Peak Period (sec)						
	9	11	13	15	17	20	Total
2.01-3.00	0.39	0.86	0.60	0.16	0.02	*	2.04
3.01-4.00	0.47	0.88	0.80	0.04	0.03	0.02	2.24
4.01-5.00	0.11	1.03	0.61	0.12	*	*	1.88
5.01-6.00	0.31	0.32	0.11	0.03	.	*	0.77
6.01-7.00	0.07	0.53	0.51	0.10	*	*	1.22
7.01-8.00	0.17	0.19	0.44	0.02	.	.	0.82
8.01-9.00	0.12	0.54	.	.	.	.	0.66
9.01 +	.	0.22	0.32	.09	.02	.	0.65
Total	1.66	4.72	3.48	0.57	0.09	0.04	10.56

* Percent occurrence is below table resolution.

Appendix B
Notation

a	Wave amplitude function
a_o	Incident wave amplitude
c	Wave celerity
c_g	Group celerity
g	Gravitational acceleration
H	Wave height
h	Water depth
i	imaginary unit = $(-1)^{1/2}$
K_r	Reflection coefficient
κ	Wave number = $2\pi/L$
L	Wavelength
n	Independent variable in the direction of the unit vector
s	Wave phase function
T	Wave period
x	Horizontal coordinate
y	Horizontal coordinate
α	Reflective component of absorbing boundary
β	Dimensionless bottom friction coefficient
γ	Phase difference between bottom friction and flow velocity
θ	Wave approach angle
λ	Complex bottom friction factor
π	3.14159.................
$\tilde{\omega}$	Radian wave frequency, intrinsic wave frequency
ϕ	Velocity potential
∂	Partial differentiation
∇	Gradient operator in two dimensions = $(\partial/\partial x + \partial/\partial y)$

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13. ABSTRACT *(Maximum 200 words)*

The U.S. Army Engineer Division, Pacific Ocean (CEPOD), requested that the U.S. Army Engineer Waterways Experiment Station numerically study the wave response of the existing harbor and five proposed plans of improvement to the small boat harbor at Maalaea Maui, Hawaii. These plans were developed to provide protection to the existing harbor. This report details the study and provides final results for CEPOD.

Deepwater wave conditions for the southwest coast of the island of Maui were established from the Monitoring Completed Coastal Projects Program measurements taken at Barbers Point, Oahu, Hawaii. The deepwater waves were transformed to the Maalaea Harbor vicinity through application of the SHALWV numerical model. The transformed wave conditions were then input to the HARBD harbor wave response model to predict the wave climate inside the harbor resulting from the existing and proposed design plans. The harbor plans were tested with waves ranging in period from 9 to 20 sec from southerly to westerly approach directions ranging from the 135.0- to 270-deg azimuth. Selected wave heights ranged from 3 to 8 ft.

The results of this study showed that Plans 1, 3, and 1a met the requirements to adequately protect the harbor from the incident wave climate. It was determined that these plans will keep the wave height in the harbor berthing areas at 1 ft or lower and in the harbor channels and turning basin at 2 ft or lower approximately 90 percent of the time per year.

14. SUBJECT TERMS

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Harbor	Numerical modeling	
Hawaii	Wave refraction	

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